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NAVY PIER CONCEPTS
REPORT NO. 1/84

INSTANT ANCHOR FOR THE EXPEDITIONARY PIER

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

Anchoring systems for a large floating pier are discussed, including stiff leg systems, single-point mooring, and dynamic positioning. A survey of anchor types is provided, and a composite mooring system called the "Self-Contained Mobile Anchor" is presented. The moored behavior of a large floating pier is addressed, and it is concluded that a single-point mooring would be the best wat y to position the pier.

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INSTANT ANCHOR FOR THE EXPEDITIONARY PIER

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INSTANT ANCHOR FOR THE EXPEDITIONARY PIER

1. INTRODUCTION

As a means to keeping a floating vessel on station, the anchor has been as common as the oars and the sails since man first ventured out into the open sea. As with the other components of the marine industry, the anchor has undegone continuous changes in form, shape, type and size to match the development of the sea-going vessels. One of the most ardent contributors to anchor technology in recent years has been none other than the Navy's own civil engineering laboratory (NCEL) in Port Hueneme, California. NCEL's publications on this subject have covered the development of practically all types of advanced anchoring systems to meet the increasing needs of the Navy. Another important contributor has been the petroleum industry. In its advance on offshore oil and gas resources, it has brought about the rapid development of offshore technology that included vessel stationing technology. The dynamic positioning system for example, is an offshoot of this advance.

The instant anchor is one of the four concepts selected for further development by T.Y. Lin International during their current contract year and new pier concepts with the Office of Naval Research, that began in August 1983. This further study is considered a necessary step toward closing the technological gap that separates the expeditionary pier (see Fig. 1) from the state of the art (SOA).

It is necessary at this juncture to modify two earlier descriptions of the nature of the present study on the instant anchor. The first is its designation as the "stiff-leg instant anchor." This designation is not appropriate, as it implied limitation of the study of anchors that are connected to the pier only by stiff legs. This should not be so, since the only "sine qua non" is the instancy of the anchoring device, and not its attachment to the vessel.

The other modification refers to the implied limitation of solution to suction type anchors only. The suction anchor will indeed receive prime consideration as a solution, because of its potentials. The exploratory nature of the study however, would require it to include consideration of other available advanced anchor types, as well as to offer new solutions of its own.

The report will generally follow the same format as adopted in previous reports. It will cover:

(a) The investigation of the validity of the concept based on a set of assumed design and construction conditions and criteria, and

(b) The investigation of the concept feasibility with respect to SOA technology.

2. APPROACH METHODOLOGY

It will first be necessary to carry out an order-of-magnitude verification of the design forces that had governed the earlier development of the instant anchor concept. The check could be made with the help of a number of computer programs available today. For this study, the OSCAR program has been used. Since the study is concerned only with order-of-magnitude values, the analyses will be carried out only as far as the following purposes are achieved:

(a) Determine the general behavior of the stiff leg.

(b) Determine the hydrodynamic properties and responses of the pier, and

(c) Determine the design forces that will act on the anchoring system.

A brief description of the theory, the analytical model used, as well as the results, and conclusion are included under Appendix A at the back of this report. The analyses and the survey of possible advanced anchoring systems, set the stage from which a new workable anchoring system for the expeditionary pier may evolve.

3. STIFF-LEG VERSUS MOORING LINE CONNECTION WITH PIER

The stiff-leg connection as previously envisioned for the expeditionary pier is shown in Fig. 3. It has the advantage of avoiding the problems with mooring line connection including storing and handling the massive mooring lines, cable fouling and entangling during slack water.

It now appears from the analyses that the stiff-leg solution will beget more problems than it solves. Firstly, it lacks the flexibility of adjusting the length of the connection to the changes in water depth. The stiff-leg connection will require universal joints at both ends which could add considerably to the cost and the risk of failures. The most serious drawback however, is having to resist the axial compression in the compression-tension stress cycle, as the vessel heaves and surges with each wave.

The mooring line connection therefore turns out to be a more logical solution in comparison, although it is not without its difficulties. It simplifies the connection problems, since more degrees of movement are permitted by a flexible line. The oscillatory forces on the anchor caused by the waves are also drastically reduced.

3.1 Mooring Line

A chain mooring line would be ideal for a single-point mooring (SPM),

because its weight allows the line to form a catenary that reduces uplift on the SPM. For the mooring force of 2,000 kips under consideration, a chain line with a diameter of 6" weighing 335 plf would be required. Numerical details showing the chain length required for water depth of 90 ft are included in Appendix A. A chain line is however costly and heavy. Its operation is time-consuming, and it poses problems in storage, handling and connection to the SPM, assuming the latter to be installed independently of the mooring line.

The polyester fibre rope could be a good alternate. It is more economical, corrosion-resistant, lightweight, and easier to handle. For it to assume the catenary shape, however, weights would have to be attached at various locations along the line. If the presently available "KEVLAR 29" is used, a mooring line of 9 - 2-1/2" dia. ropes bound together, weighing only 17 plf in air, can provide a breaking strength of 4000 kips. This is however much more costly than the fiber ropes in commoner use at this stage of its development. However the cost could be expected to go down as its use is increased with time. Its use has been conceptualized in illustrations shown in Figs. 4 and 5, and also pp. A-23 - A-25 in Appendix A.

4. THE SINGLE-POINT MOORING INSTANT ANCHOR

What distinguishes the instant anchor from the conventional anchor is of course its "instancy", which is a measure of its responsiveness to the requirement of the expeditionary pier. The rationale behind the instant anchor had been briefly touched upon in previous reports. For the sake of the completeness of a report that it dedicated to its development, it is reproduced below:

(a) For the expeditionary pier to be effective, it should be large enough to accommodate say six combatant ships of the destroyer class.

It should be self-sufficient, so as to be able to operate in far away places for an extended period of time, and it should be capable of rapid relocation and deployment. The value of such a pier would be greatly enhanced, if it is endowed with the capability to go into action immediately upon arrival at site, or to depart at short notice. An anchor that could be installed or retrieved quickly, say within an hour, would be in keeping with the nature and the purposes of the expeditionary pier.

(b) In order to minimize the huge environmental forces the pier/ship complex would impose on the anchoring system, the pier should be made to head the sea at all times. These requirements would point to the single-point mooring (SPM) as the most suitable anchoring system for the pier.

(c) Possible reversal of flow direction in channels due to tidal changes, etc., will require the anchoring system to provide the full holding capacity in any direction. If the SPM is used, it will have to include the use of a swivelling connection to the mooring line.

(d) The concentration of holding power in one single anchor will greatly facilitate the installation and retrieval processes, and enhances its "instancy".

5. DESIGN CONSIDERATIONS AND ASSUMPTIONS

Major design considerations and assumptions that are used in developing the instant anchor, are summarized below:

5.1 Design Considerations

(a) The anchor will lend itself to rapid installation and retrieval.

(b) It will permit the pier to head the sea at all times.

(c) It will provide the full holding capacity in any direction.

(d) It will be easy to maintain and

(e) It is reusable.

5.2 Assumptions

(a) The soils are penetrable to the depth necessary to provide the required holding force.

(b) Water depth is generally in the order of 150 ft.

(c) For the purpose of a study design, the pier is assumed to be anchored in sheltered waters, and not exposed to storm condition in excess of Sea State 4, and

(d) Mooring ships are assumed to cast off and ride out a storm by themselves, should the risk of anchor failure exist.

6. SURVEY OF STATE OF THE ART ANCHORING SYSTEMS

The requirement of instancy and minimum environmental forces will rule out anchoring systems that require long installation and retrieval times, and those requiring fixed orientation of the pier. Because the anchor has to be operational in any direction, the most likely solution would be a SPM that has the form of a vertical, cylindrical anchor structure that has the capability of

burrowing itself into the soil. The structure will be designed to resist the tremendous shear and bending moment caused by a horizontal pull topside.

Several SOA techniques are available to sink the anchoring structure to a required depth into the sea bottom, or otherwise keep the pier on station:

(a) The suction anchor.

(b) The propellant-embedded anchor.

(c) The drilled-in anchor.

(d) The deadweight anchor.

(e) Dynamic positioning.

(f) Combination of (a), (b), (c) and (d) above with jetting.

These methods have the following common attributes:

(a) Large holding capacity in any direction.

(b) Installation in controlled conditions.

(c) High capacity/self-weight (C/SW) ratio. E.g. the conventional fluke anchor in sandy soil may have a C/SW of 2. Suction anchor of the same weight could increase this ratio by a factor of 4.

6.1 Suction Anchor

Only the surface-attached, or the semi-buried type of suction anchor will

be considered, since the presence of the swivelling joint and the umbilical connections to the top of the anchor will not permit complete burial. The anchor may be equipped with a jet ring to facilitate and accelerate its descent into and withdrawal from the bottom of the sea.

A graphic presentation of the suction anchor concept that has been designed for the expeditionary pier is shown in Fig. 7.

The advantages of the suction anchor, as reported from experience, include the following:

(a) Easy handling.

(b) Simple equipment for installation. These generally consist of submersible pump and light crane on board the anchor vessel.

(c) Rapid installation. Penetration rate of 15cm - 30cm per minute has been reported.

(d) Instant load application after installation.

(e) Full holding strength in all directions, and

(f) Possibility of recovery.

These advantages refer to the self-buried type of anchor. The possibility of recovery will be much greater with semi-buried anchors.

6.1.1 Design

The process of designing a semi-buried cup type suction anchor suitable for the use of the expeditionary pier is presented in a set of calculations and worksheets shown under Appendix B at the back of this paper. The process begins with a brief parametric study to provide baseline data on the effect and influence of various parameters on anchor capacity. The state-of-the-art technology is used throughout the design process. The results indicate that for the suction anchor to provide the holding capacity of about 3,000 kips ultimate, with a buried depth of 20 ft, the diameter of the suction anchor would be in the order of 50 ft. This is shown in Fig. 7. To facilitate the descent and the withdrawal of the suction cup, a ring jet around the lower edge of the anchor, as shown in the illustration, could be used.

6.1.2 Details

Details that have to be worked out include the swivelling joint on the top of the anchor, an arrangement to avoid the fouling of the mooring line with the umbilical cables, and the means to keep the mooring line as close to horizontal as possible, and to reduce the uplift on the anchor.

As shown on the graph on Page B-5 in the worksheet, under Appendix B, the efficiency of the suction anchor against hori-horizontal pull and uplift increases with the increasing horizontality of the mooring line. Both will also increase with the depth of penetration into the soil.

6.2 The Propellant-Embedded Anchor

The embedment of anchor by propellant is one of the simplest and fastest ways of anchor installation. The method has been used with success in a number of occasions by the Navy. Unfortunately the technology developed so far has been limited only to the buried type of anchor. This essentially consists of a folded fluke, or a plate, which is propelled into the soil by explosive force. The explosion is controlled by a sensoring device, and is set off when the anchor package touches bottom. The plate or the fluke is then keyed or set against the overlying soils, and the anchor is ready for use. This type of anchor has shown high efficiency. It has been tested to holding capacities of up to 400 kips, with embedment depth varying from 20 ft in sandy soil to over 40 ft in soft mud.

The propellant-embedded anchor could conceivably be developed to handle the much larger holding capacity required for the expeditionary pier. It does meet all major criteria except two:

1) The irretrievability of the anchor, and

2) The preclusion of swivelling joint at the surface of sea floor.

The loss of a massive anchor assembly after every use is a distinct disadvantage. Besides the consideration of loss, there is also the additional problem of storing a number of spare anchor assemblies or clusters on board, and of handling the massive weight when replacing one that has been lost in previous use.

6.2.1 Design

The development of a propellant-embedded anchor is shown in the

worksheet under Appendix B. Again, as for the suction anchor, a parametric study to determine the influence and effects of various parameters on the capacity of the anchor was first carried out. Serious limitation of the propellant-embedded anchor is the size of the plate or fluke that can be driven into the soil by this method. For this reason and also for the fact that it is not possible to develop a swivelling joint for this anchor, it is not further considered in this study.

6.3 Drilled-in Anchor

As its name implies, the anchor is secured to the sea bottom by augering into the soil to the required depth. It has a number of disadvantages. It is slower, and it cannot achieve high capacity because of limitation of auger size and power required. An improvement would be to bundle several drills together, each in its own cylindrical enclosure, into one large unit. The difficulty here is with the control of the drilling rates and the reliability of the performance of the auger in each cylinder. The process will be seriously jeopardized and put out of control, if any auger in the bundle fails to perform as designed. In order to provide the necessary reaction for the rotating tendency of the anchor during drilling, it will be necessary to develop a drill bundle in units of two drill cylinders, and rotating the two drills in each unit in opposite direction to cancel the effect of rotating tendency by each drill. A sketch showing the multi-cylinder drill bundle is shown in Fig. 8.

6.4 The deadweight Anchor

The holding power of a deadweight anchor is derived primarily from its own weight. Other contributors include soil friction or adhesion on

contact surfaces, and suction on the underside of the anchor. The latter is particularly effective against transient loads.

Deadweight anchors, or gravity anchors as they are called in the offshore field, are generally made up of several steel or concrete boxes that are ballasted to increase their weight after they are placed on the sea floor. The commonest ballast are sand and gravel. But concrete, iron ore and other dense heavy materials have also been used. Considerable amount of knowledge in gravity structures is already available from experiences offshore.

In its application to the Navy's expeditionary pier, the deadweight anchor does offer the advantage of rapid emplacement. However the ballasting process involving ballast other than water will take much time. It is even worse in the reverse deballasting process. The anchor is also not weight-efficient. Heavy equipment will be required to handle a gravity anchor that may be as large as the one shown in Fig. 9.

For this reason and for consideration of other factors that are unfavorable to the use of deadweight anchors for the purposes of the expeditionary pier, this anchor is not considered a likely solution.

6.5 Dynamic Positioning

A survey of the SOA anchor technology will not be complete without mentioning the dynamic positioning (DP) method of keeping a vessel on station. Since the pier is expected to be equipped with its own propulsion system, it may be possible to incorporate the DP capability in the system without too much additional cost.

The biggest advantage of the DP system, besides being a truly "instant" positioning device, is in its applicability regardless of water depth. It is therefore practically the only way to go if the pier is deployed in deeper water, or in the open sea to support the occupancy of an ocean region.

The DP is sufficiently developed by the offshore industry, so that its use by a large vessel like the expeditionary pier would pose no greater problem than adapting the commercially available DP units to this new application. DP units with as much as 8 thrusters of 24,000 HP rating have been developed and used (SEDCO 709 Semi-submersible). For a holding power requirement of say 10,000 kips, 15 units of 30,000 HP units may suffice.

A possible setback in the use of DP by the expeditionary pier, could be due to the difficulty and time taken in a foreign site to locate and install a baseline system on the sea floor for DP control. The taut wire system may be simpler to use. But this also has its limitation.

It is not the intention of this report to go further into this method of keeping station, than discussing it briefly in passing. With DP technology continuing to advance, it can be expected to increase its role and its usefulness with time. For the time being, we will continue our efforts in the exploration of sea-keeping methods suitable for the purposes of an expeditionary pier in relatively shallow and sheltered waters.

7. THE COMPOSITE SOLUTION

The above exercises had pointed to an anchoring system for the pier, i.e.:

(1) Large in size,

(2) High in C/SW ratio from embedding itself in the soil, and

(3) Rapidly installable and retrievable.

The solutions according to plausible SOA anchor types, as described above, represent incremental improvements that are circumscribed by the same constraints as those before the improvement. What is needed is an advanced solution that could free the SOA anchors from their present constraints, for the use of such large vessels as the expeditionary piers, in the years ahead.

A mobile anchor that is equipped with its own systems for propulsion, ballasting, suction, jetting or other means of burrowing itself into the soil, that is either manual or remote-controlled, would be one such solution. A plausible version of this self-contained mobile anchor (SCMA) is shown in Fig. 10. The self-contained anchor may of course be lowered to the bottom by cranes on board. The idea of a manned mobile anchor is however more intriguing, and is therefore given more attention in this report.

A SCMA of say 4,000-kip capacity could be a vessel measuring 70 ft wide and 90 ft long from bow to stern, and 28 ft deep as shown in the drawings.

The SCMA is stowed at the stern of the pier, and lifted out of the water when not in use. Upon apprival at site, it is lowered into the water with the operator on board. The operator maneuvers the SCMA into position on the sea floor, and activates and controls the jetting and suction mechanisms to burrow the SCMA to the desired depth. He then releases the messenger line to the water surface, to pick up and guide the lowering of the mooring line to the swivelling joint on the SCMA. The mooring line is connected to the joint, possibly by remotely-controlled devices. The whole installation should not take more than a couple

of hours, assuming the rate of descent into the soil is the usual average of 20 cm/min. and the required depth of penetration is 15 ft.

A possible unique feature of the SCMA is the multiple usage of the thrusters. By manipulating a system of valves, the thrusters can be used to propel the SCMA, to apply suction or pressure to the suction chambers, and to force water through the jet nozzles around the lower edges of the suction chambers, to assist in the burrowing or withdrawing operations. See Fig. 11.

One version of the hypothetical SCMA for 4,000-kip capacity is represented by Fig. 10. Possible details of the swivelling joint is shown in Fig. 13. A line diagram describing the mooring operation is included in Fig. 12.

8. COST ESTIMATE

A cost estimate of the 4,000-kip SCMA, necessarily a sketchy one considering the early stage of its development, is presented herein primarily to satisfy one of the conditions of the study. The estimate is made up only for the structural steel system of the SCMA. It does not include the mechanical, electrical, hydraulic equipment, and the control system which could be several times the cost of the structure itself.

a.	Concrete at $1000/cy	$ 20,000
b.	Structural Steel at $2500/Ton	$900,000
c.	Swivel Joint	$ 15,000
	TOTAL	$935,000

9. CONCLUDING REMARKS

Inspite of some of its shortcomings (e.g. a large excursion area for the moored vessel), the SPM offers many attractive features to the users. It can be simple and fast to install. It is highly efficient for two major reasons:

(1) Unlike the multi-leg mooring system where an anchor may or may not be called upon to act depending on the direction of the flow, the SPM is used regardless of flow direction.

(2) In enabling the vessel to face the sea at all times, thereby reducing to a minimum the force necessary to keep it on station, the SPM is in fact equivalent to an anchor 3 or 4 times its size in a multi-leg system that resists wave and current forces approaching the vessel on the broadside.

Although large SPM's for offshore applications by the petroleum industry have been built, they all have been site-specific, permanent structures that are expected to more than pay for themselves from many years' operation. SPM's that have to be carried by the ships are necessarily limited in size and capacity. The SCMA could well be the next generation ship-carried SPM because it frees the present SPM from the constraint of size. It is conceivable that the removal of this constraint will open up new possibilities for the use of the SCMA, not only for anchoring large vessel complexes like the expeditionary pier, but for other purposes that require the use of underwater surface-attaching crafts.

This report has omitted a section on the identification of problem areas as was wont with previous reports. This is done for a good reason; the entire concept of the SCMA is novel and requires almost every component of the invention to be further researched. Considerable work to develop the SCMA into an operational anchor lies ahead, should its potentitals justify further pursuit.

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FIGURES

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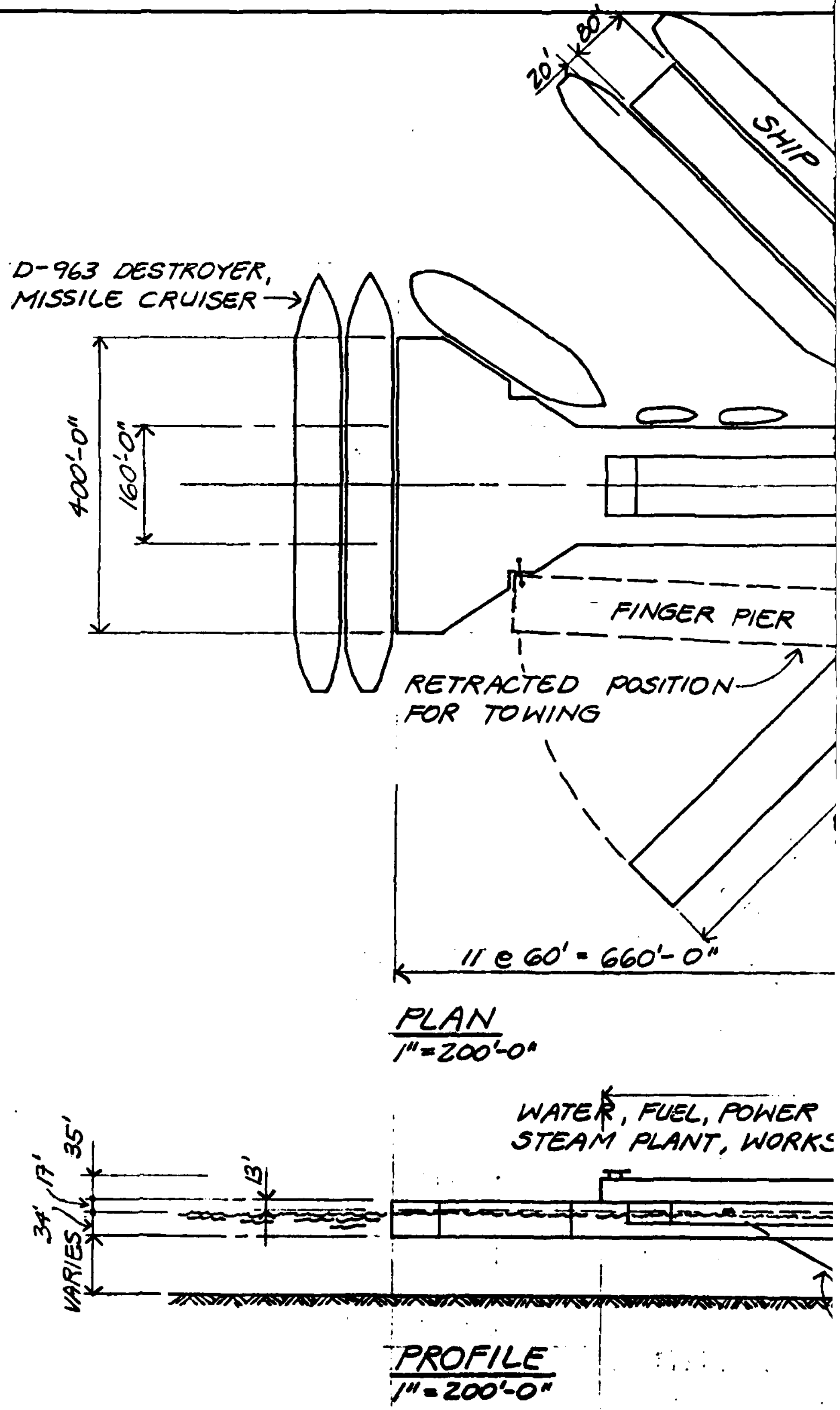

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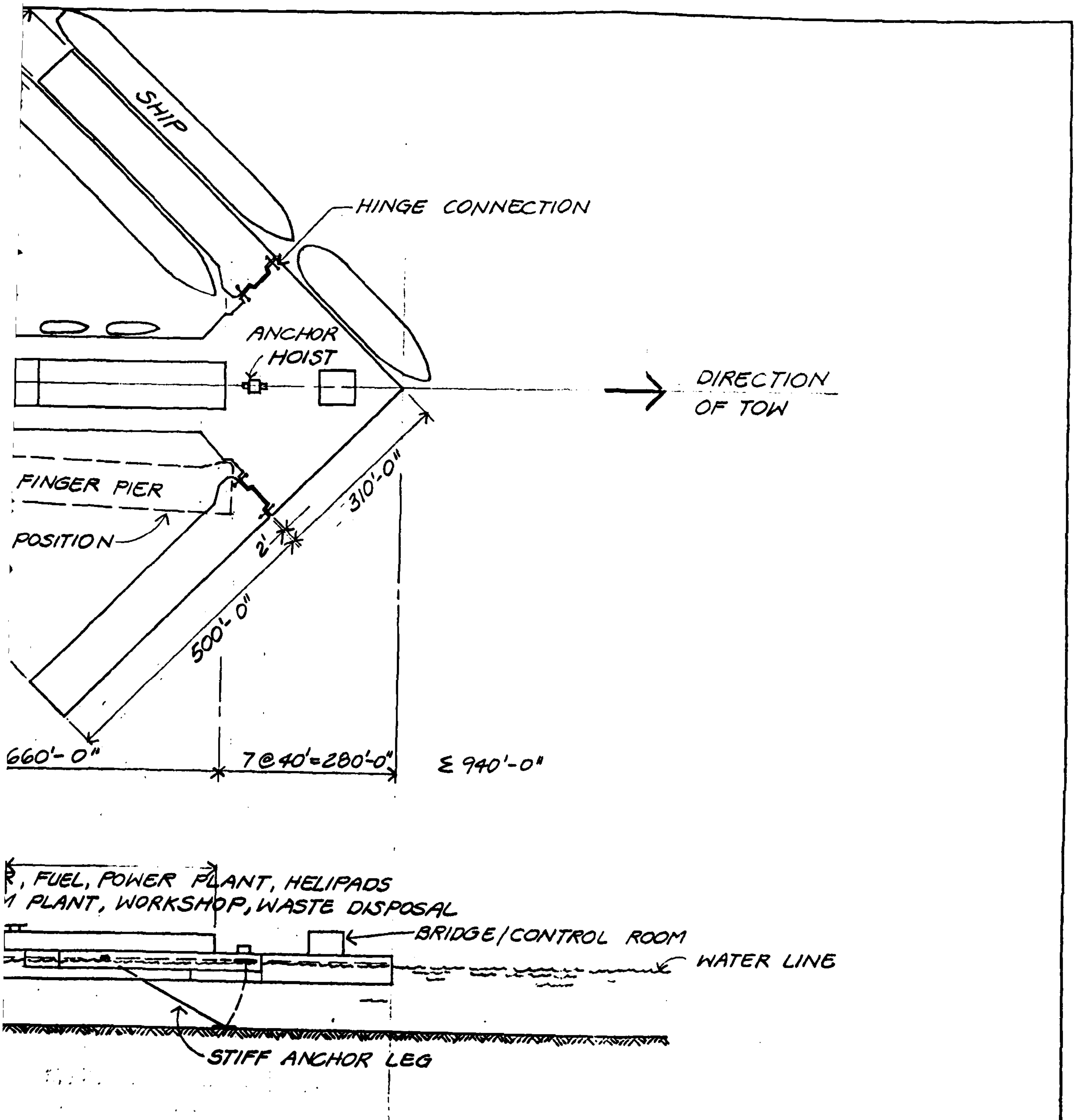

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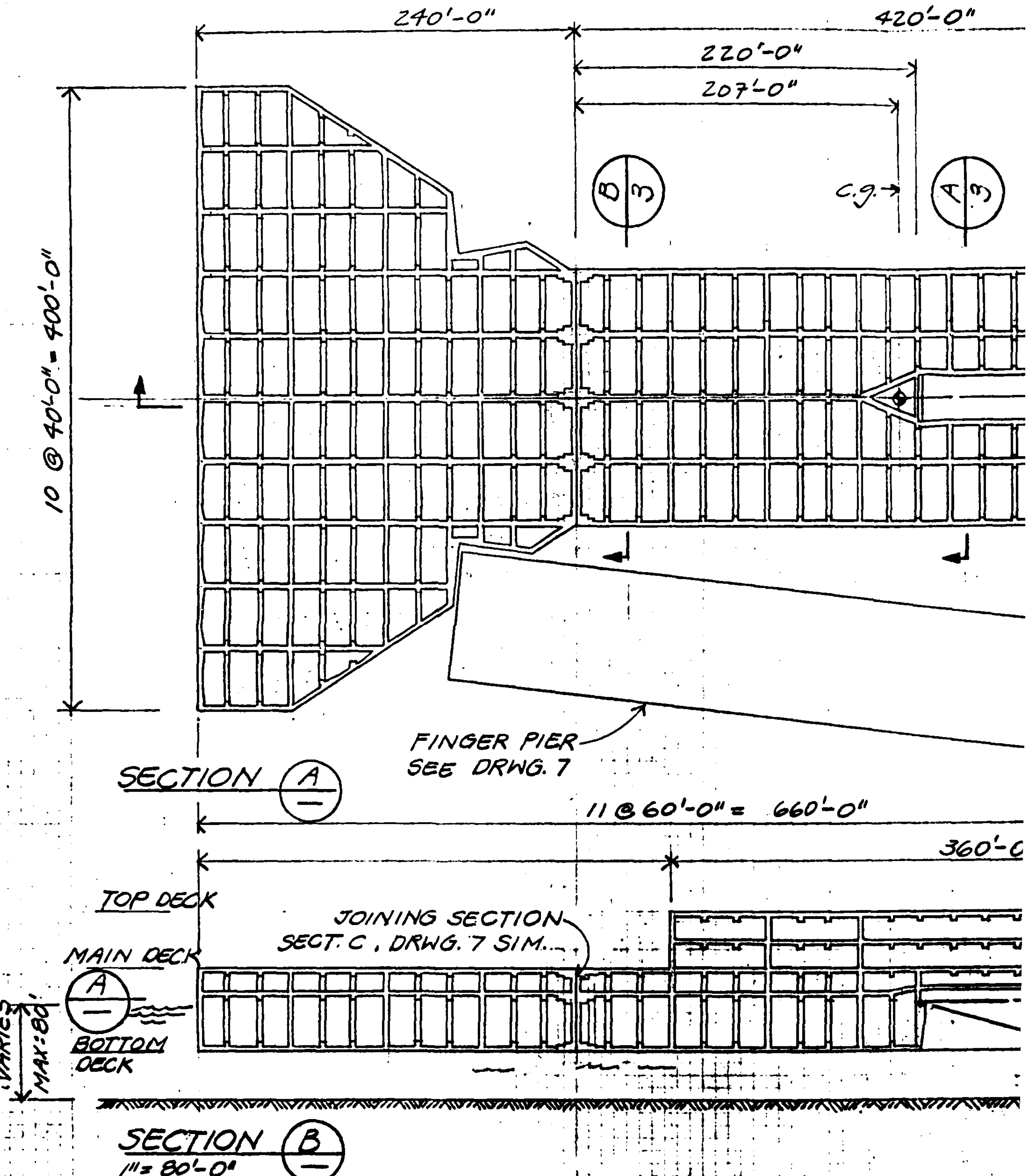
SHEET TITLE: SCHEME A

PROJECT: EXPEDITIONARY PIER

SHEET Nº 1



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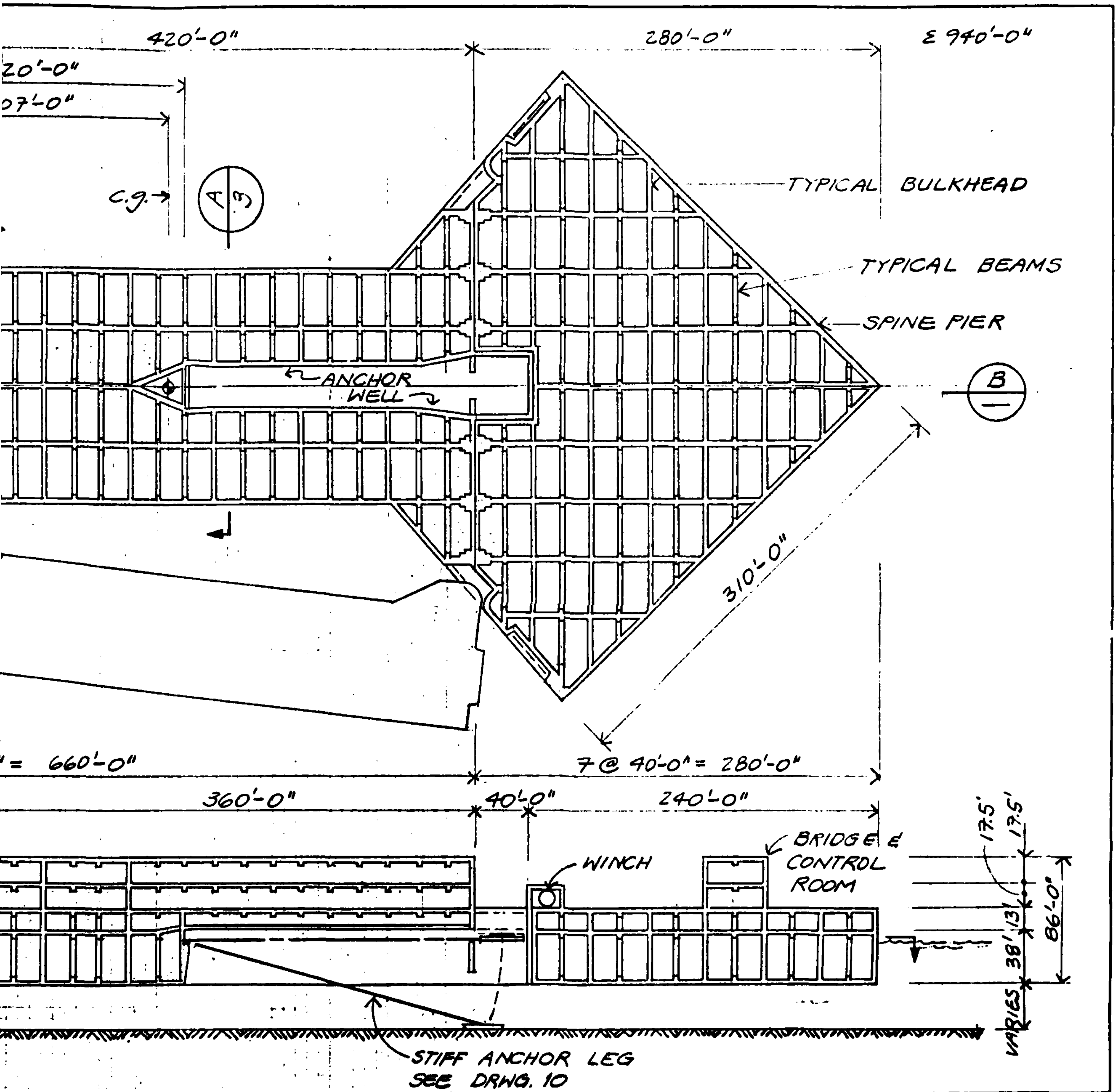

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PROJECT: EXPEDITIONARY PIER

SHEET Nº 2

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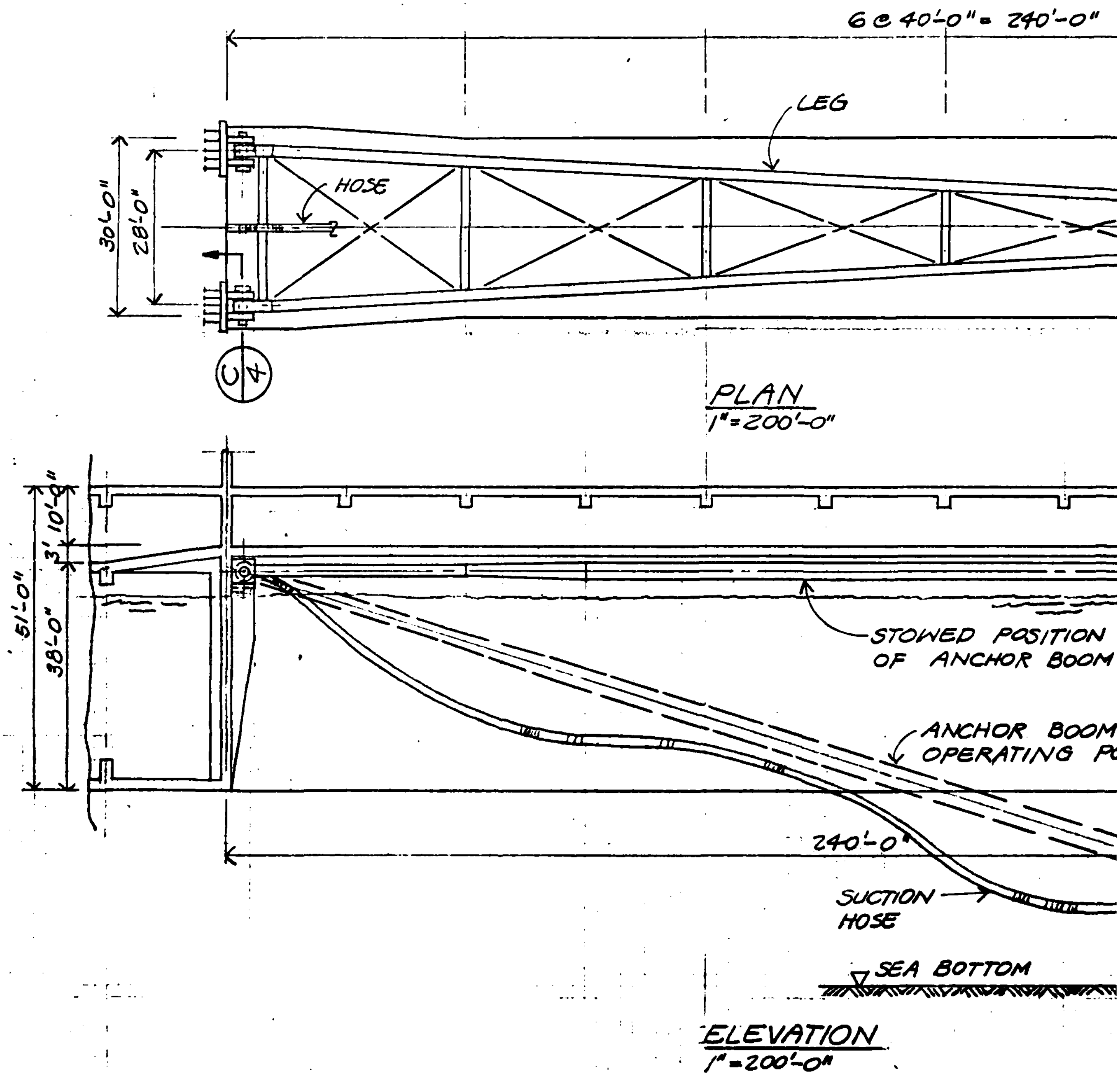

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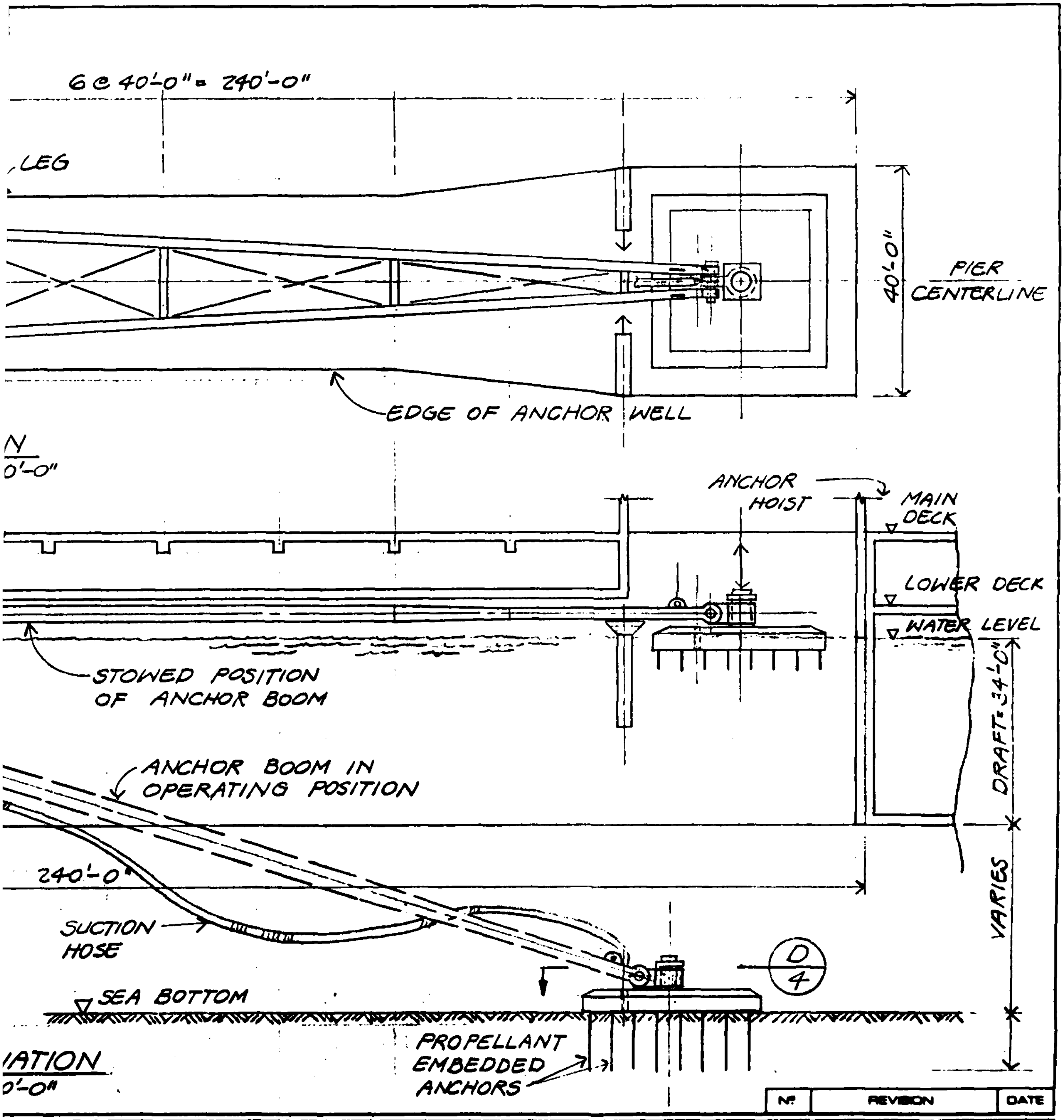

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SHEET TITLE: STIFF LEG ANCHOR

PROJECT: EXPEDITIONARY PIER

SHEET Nº 3

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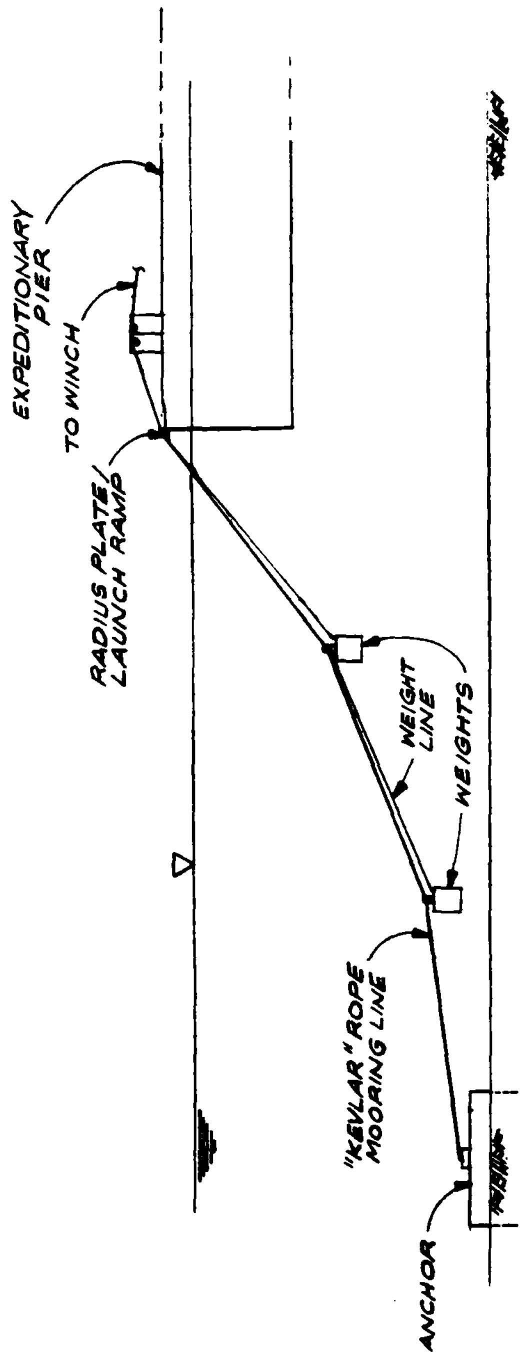
PROJECT:	NAVY PIER CONCEPTS
ITEM:	INSTANT ANCHOR FOR EXP PIER
DESIGN:	KEVLAR ROPE SINGLE POINT MOORING
DATE:	

SHEET: Fig 4
OF
REVISION:



"KEVLAR" ROPE SINGLE POINT MOORING

Fig. 4

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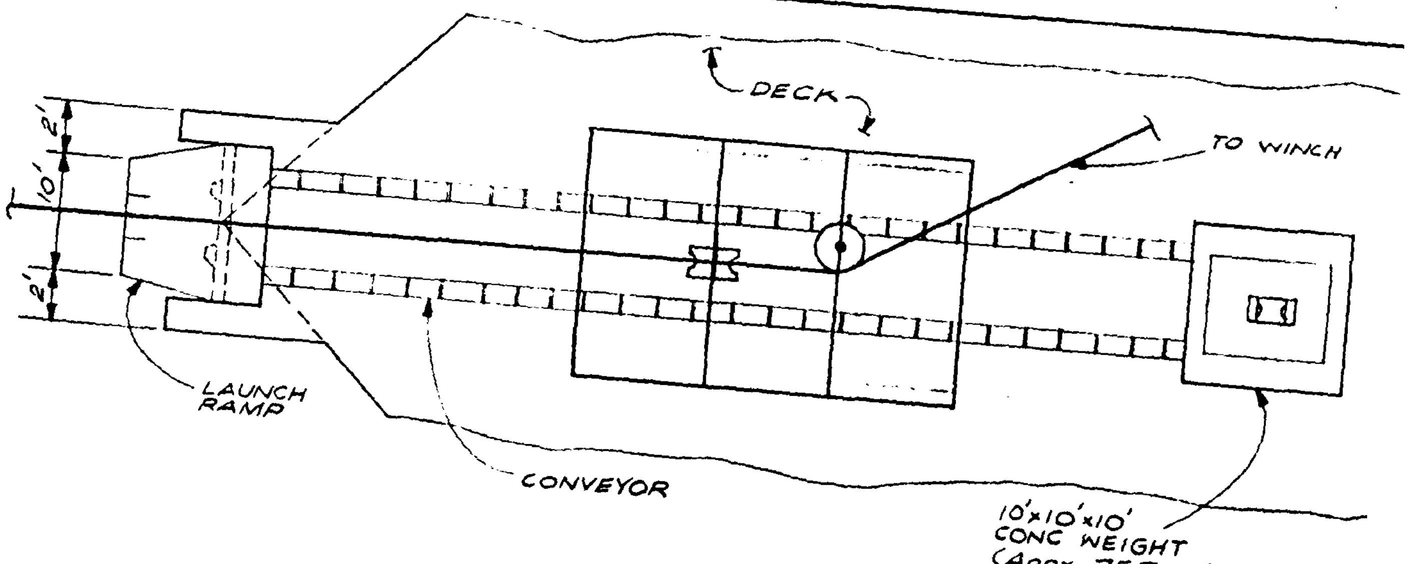
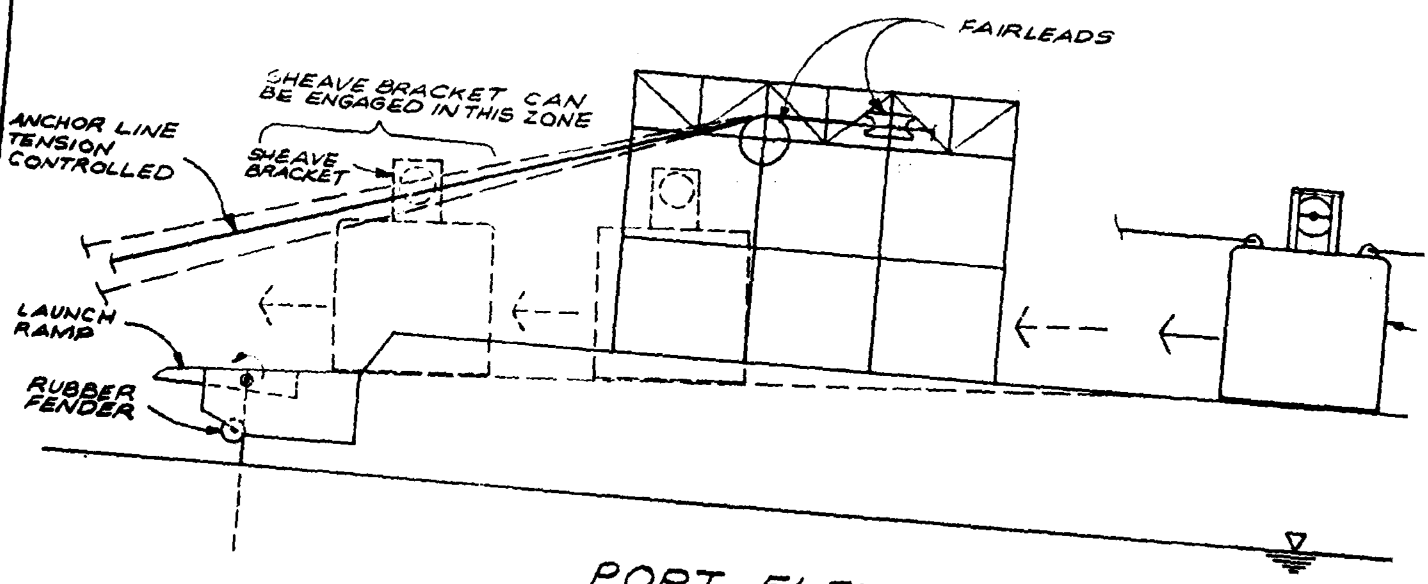


TOP VIEW
1" = 10'



PORT ELEVATION
1" = 10'

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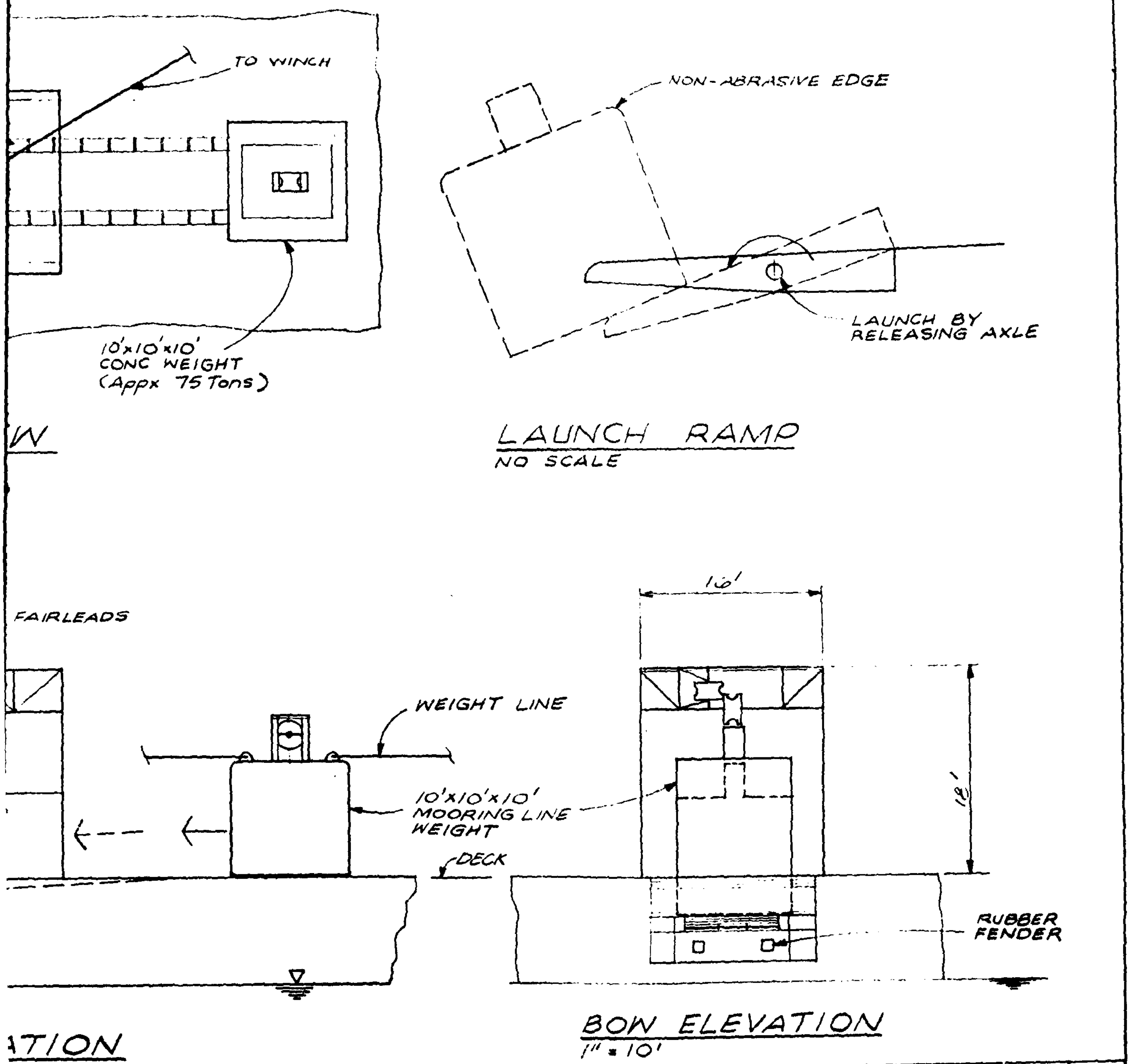

N°	REVISION	DATE

Issued For	Date	By

SHEET TITLE: **MOORING LINE WEIGHT LOADING ASSEMBLY**

PROJECT: **INSTANT ANCHOR FOR EXPEDTIONARY PIER**

SHEET N° **5**

2

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PROJECT:	NAVY PIER CONCEPTS
ITEM:	INSTANT ANCHOR FOR EXP. PIER
DESIGN:	SHEAVE BRACKET
DATE:	

SHEET: 6
OF
REVISION:

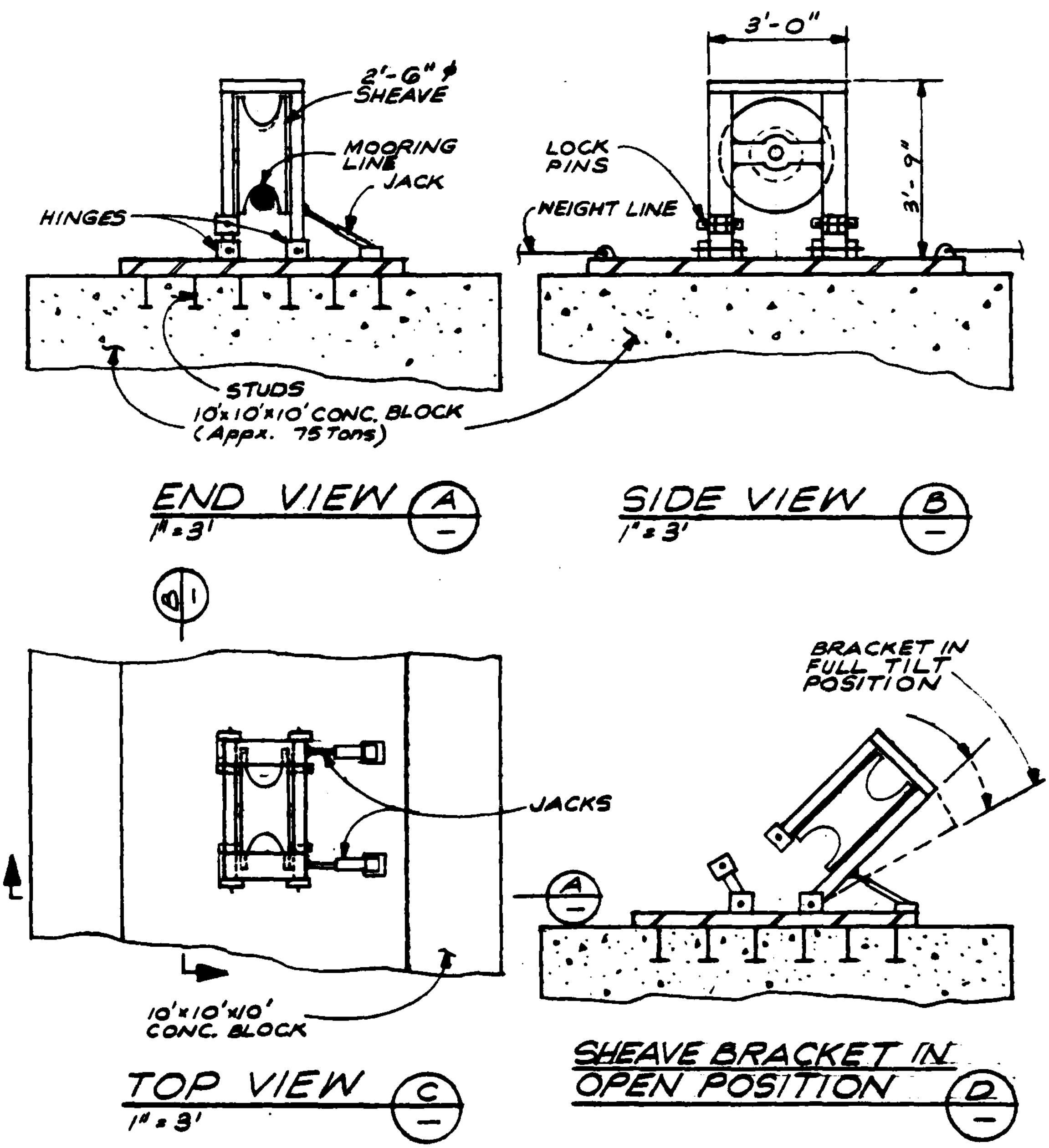

Fig. 6

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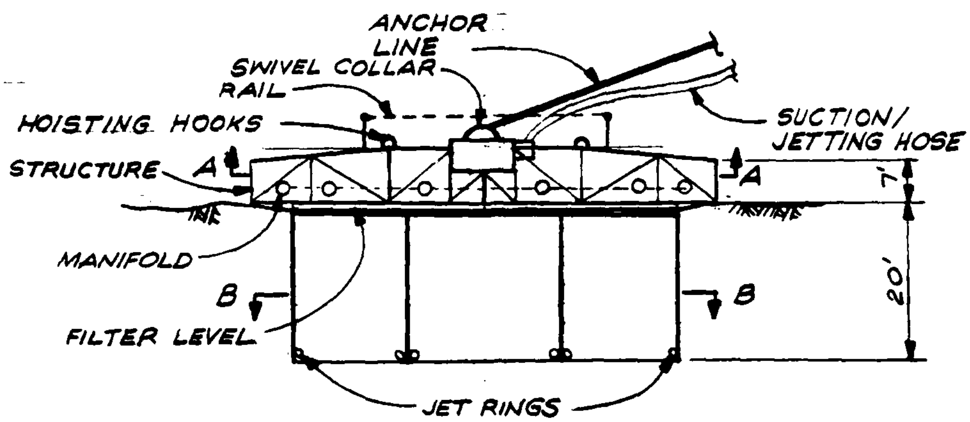
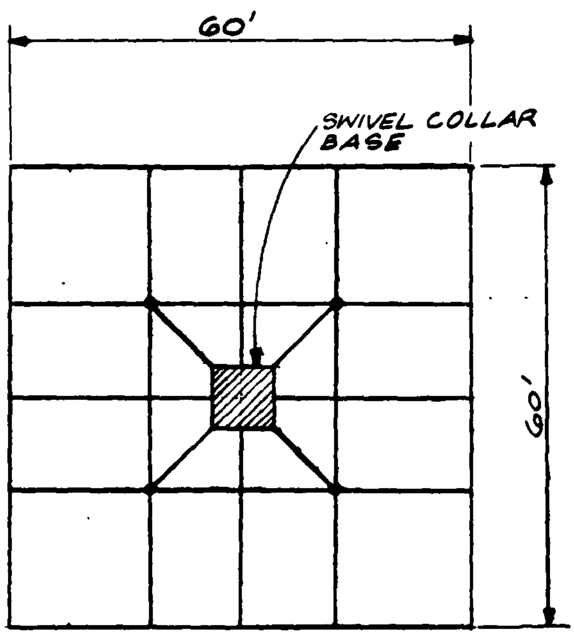
PROJECT:	NAVY PIER CONCEPTS
ITEM:	INSTANT ANCHOR FOR EXP. PIER
DESIGN:	SUCTION ANCHOR
DATE:	

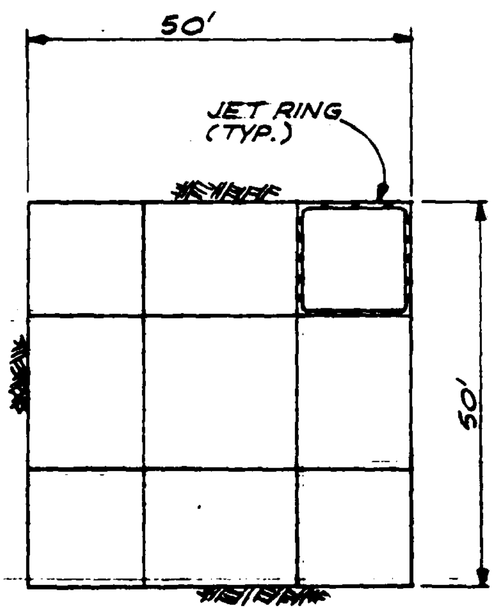
SHEET: Fig. 7
OF
REVISION:



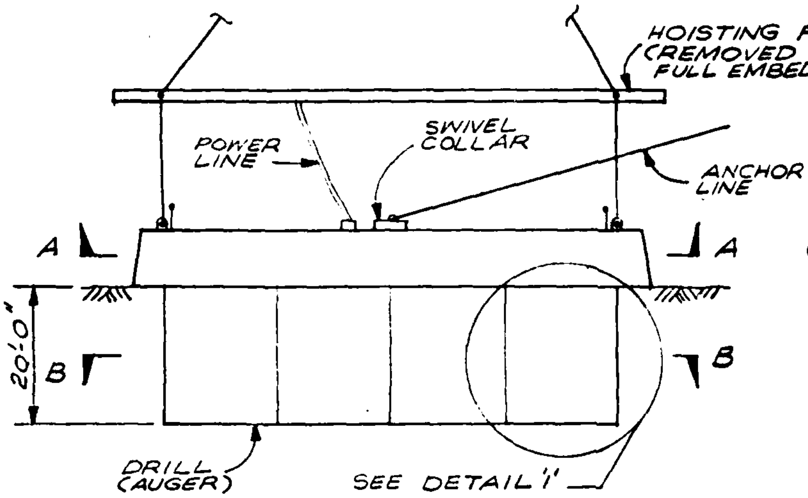
LONGITUDINAL SECTION
1" = 20'



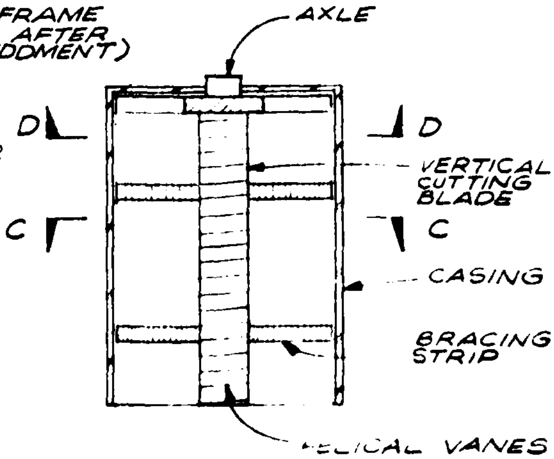
SECTION 'A'-'A'
STRUCTURAL SCHEME



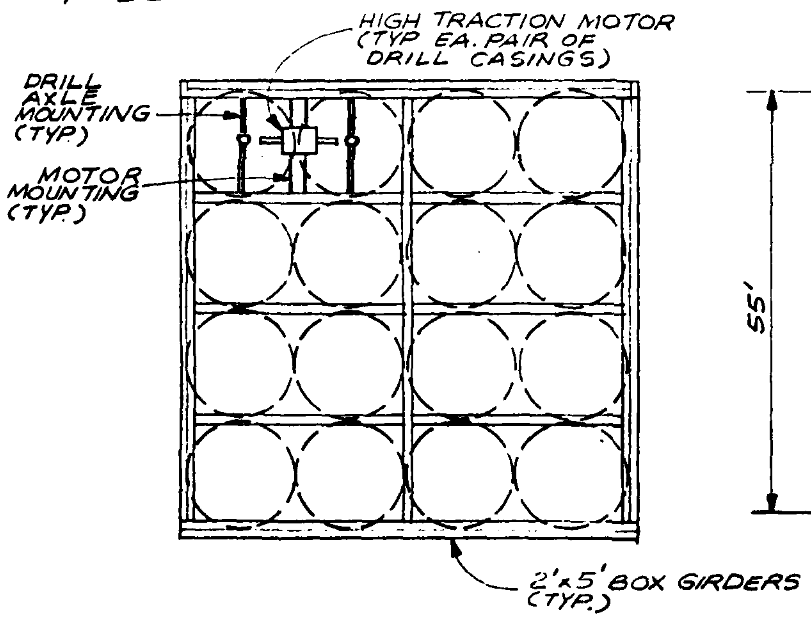
SECTION 'B'-'B'
SUCTION COMPARTMENTS



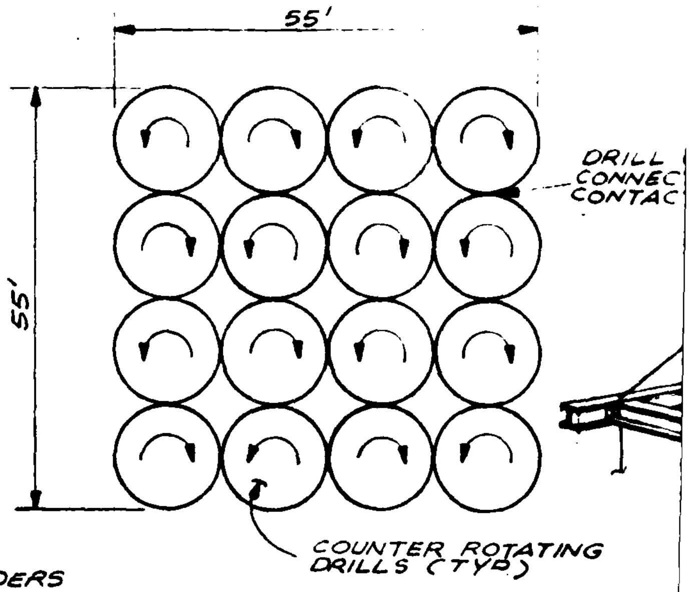
DRILLED-IN-ANCHOR ELEVATION
1" = 20'



DETAIL '1'
1" = 10'



PRIMARY STRUCTURAL SCHEME
SECTION 'A'-'A'
1" = 20'



SECTION 'B'-'B'
1" = 20'

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PROJECT Nº

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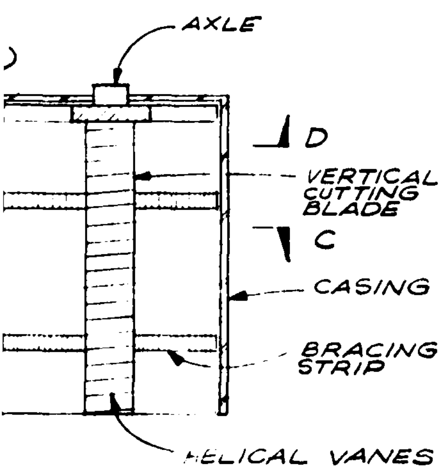
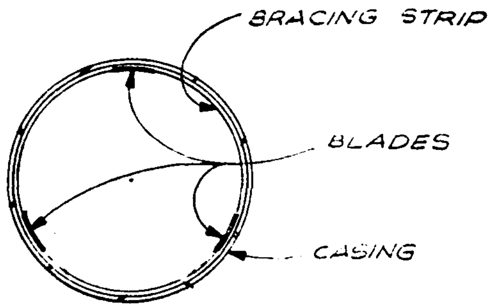
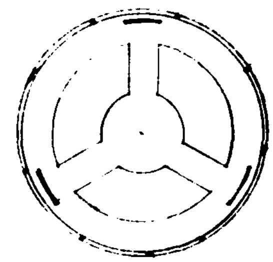


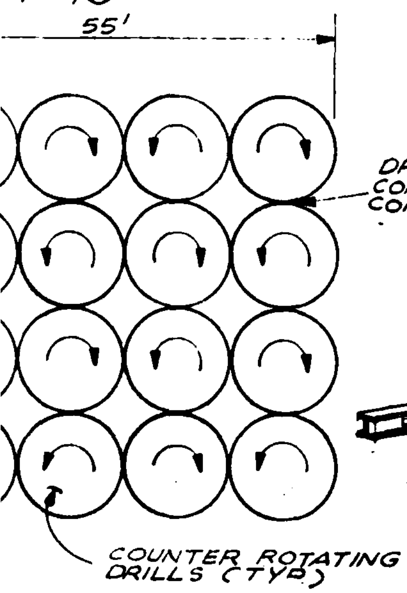
DETAIL '1'
1" = 10'



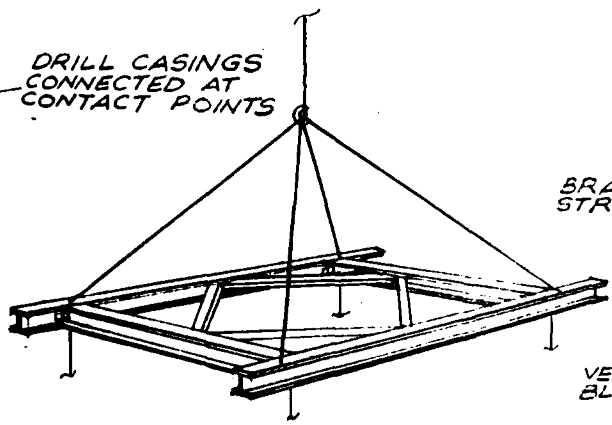
SECTION 'C'-'C'
1" = 10'



SECTION 'D'-'D'
1' = 10'



ECTION 'B'-'B'
= 20'



HOISTING FRAME
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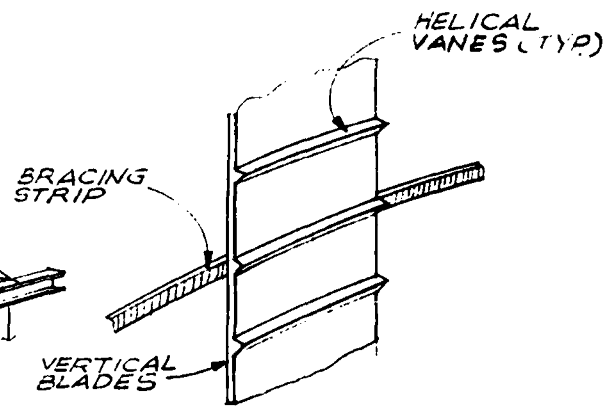


CUTTING BLADE DETAIL
NO SCALE

Nº	REVISION	DATE

Issued For	Date	By

SHEET TITLE: DRILLED-IN ANCHOR

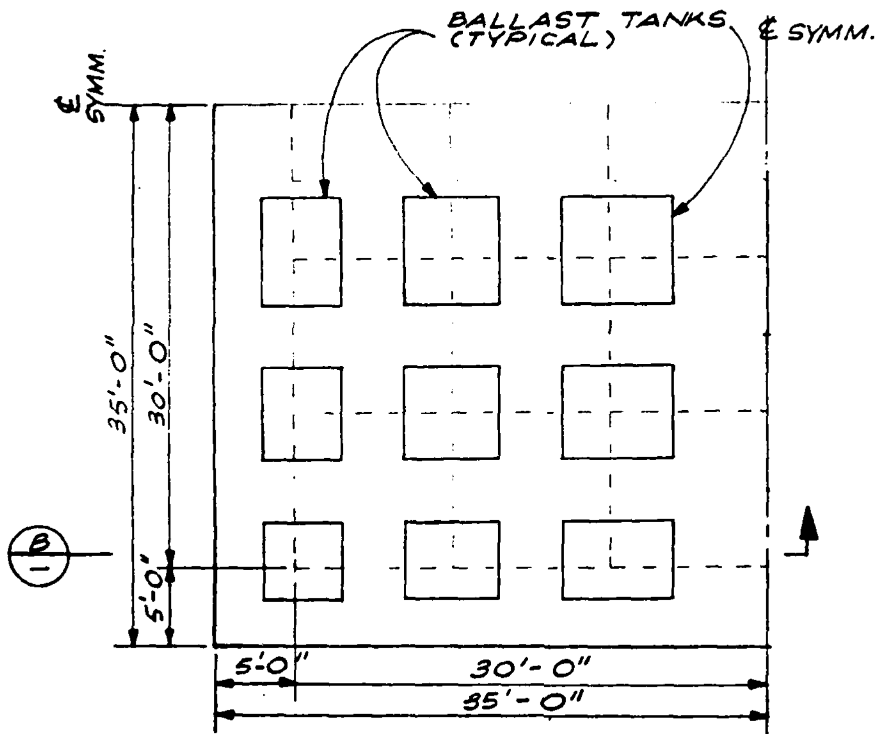
PROJECT: INSTANT ANCHOR FOR EXPEDTIONARY PIER

SHEET Nº 8

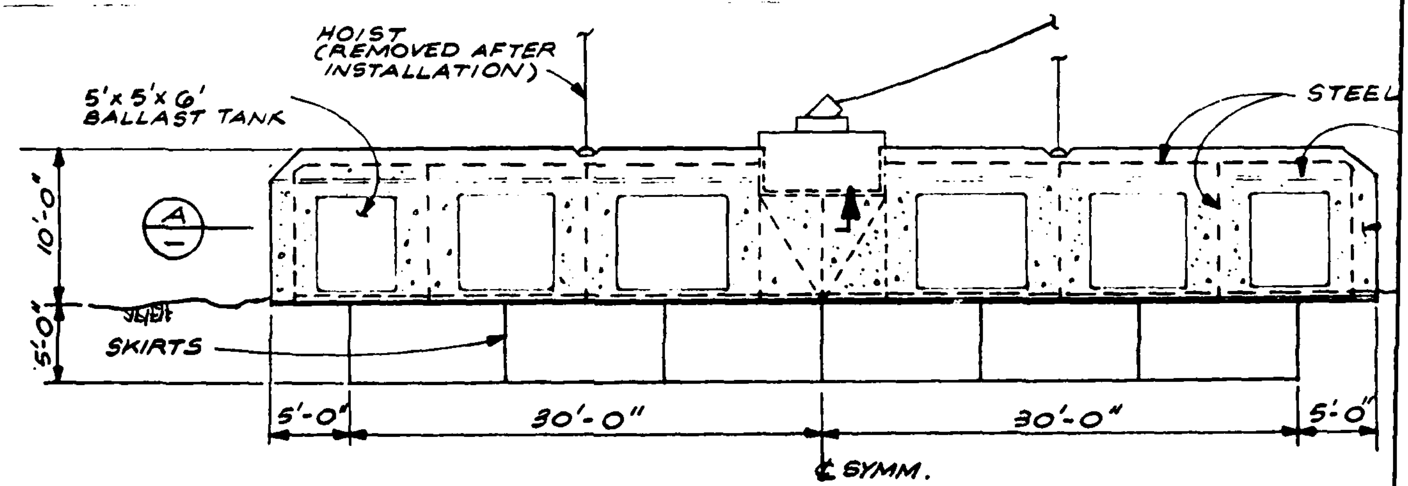
DRAFTING

DESIGN

PROJECT Nº



PLAN SECTION (A)
1" = 10'



TRANSVERSE SECTION (B)
1" = 10'

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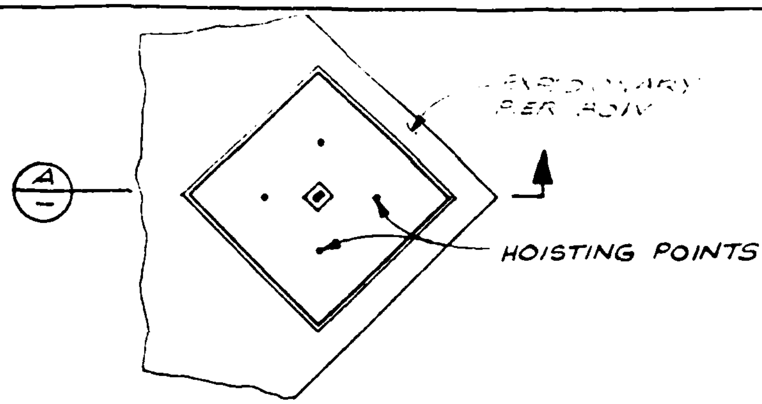
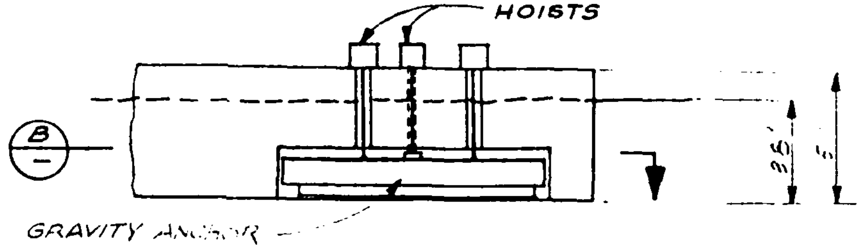
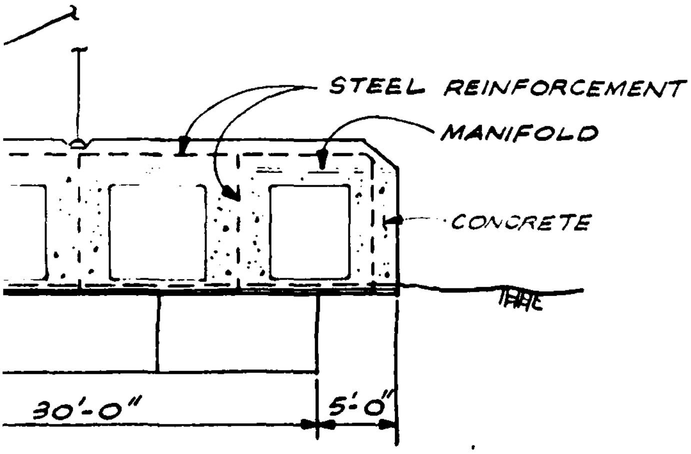


DETAIL 1
1" = 60'



DETAIL 2
1" = 60'

GRAVITY ANCHOR STOWAGE



ECTION B

PROPOSED GRAVITY ANCHOR FOR EXPEDITIONARY PIER:
(Appx. 2600 Kips Capacity)

- CONCRETE 1890 CY
  SUBMERGED WEIGHT 2200 Tons
- VOID VOLUME 290 CY
- TANKS BALLASTED WITH SEA WATER DURING OPERATION
- DURING HOISTING, TANKS DEBALLASTED WITH COMPRESSED AIR TO PROVIDE 250 TONS UPLIFT.

Nº	REVISION	DATE

Issued For	Date	By

SHEET TITLE: GRAVITY ANCHOR		SHEET Nº 9
PROJECT: INSTANT ANCHOR FOR EXPEDITIONARY PIER		

2

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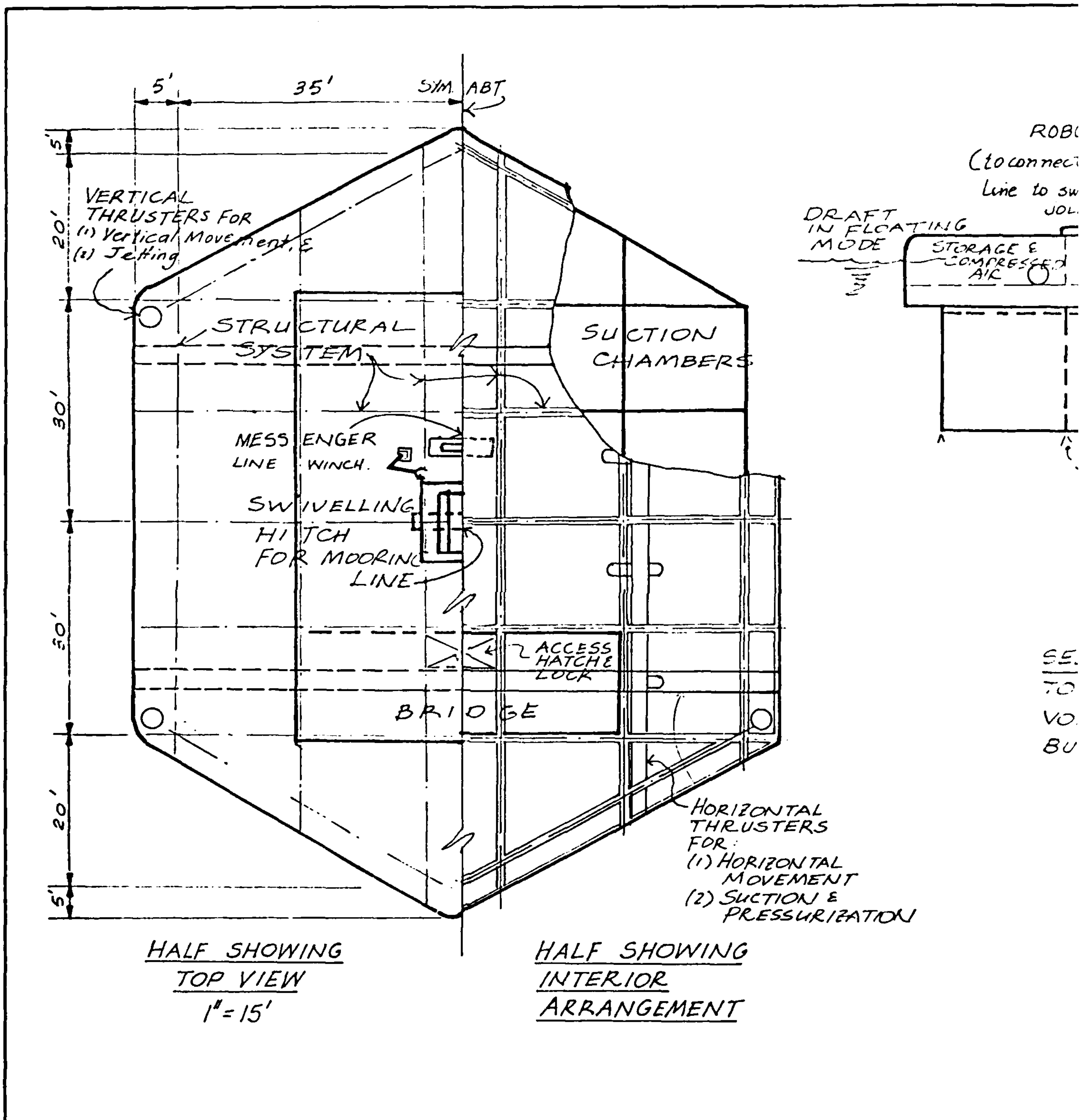
DESIGN
PROJECT Nº



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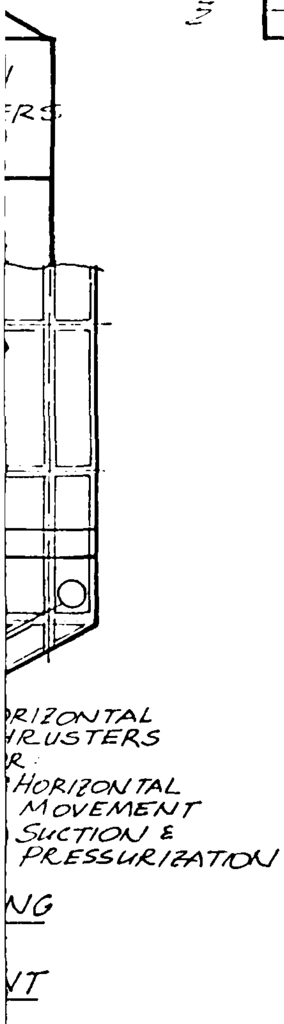

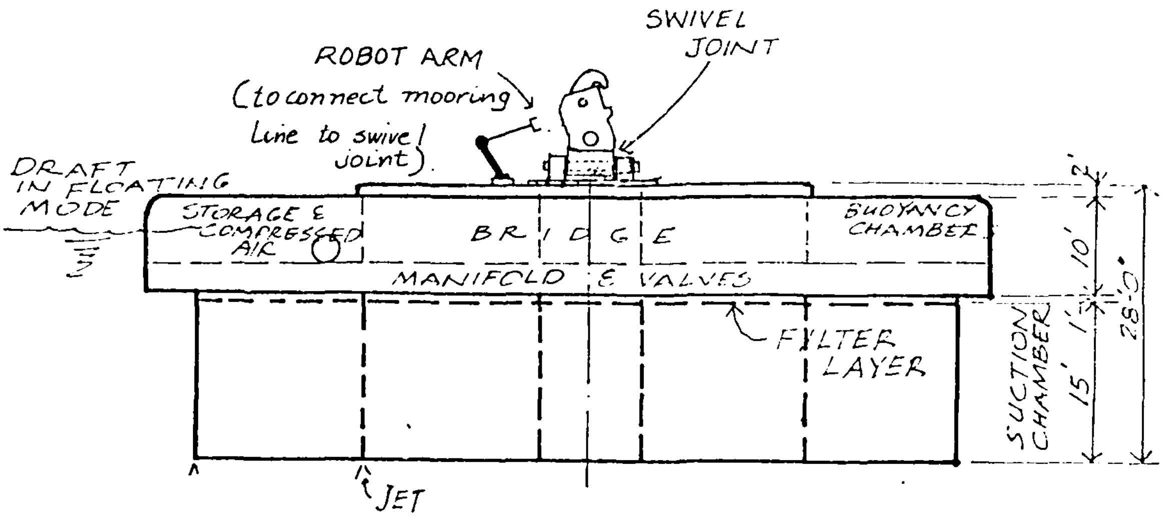

BOW ELEVATION

SELF CONTAINED MOBILE ANCHOR (SCMA)

TOTAL WEIGHT IN AIR : 1400 TONS Appx.

VOID SPACE REQUIRED FOR NEUTRAL BUOYANCY : 37500 FT.^{3} Appx.

Issued For	Date	By	Nº	REVISION	DATE

SHEET TITLE: SELF CONTAINED MOBILE ANCHOR		SHEET Nº
PROJECT: INSTANT ANCHOR FOR EXPEDITIONARY PIER		10

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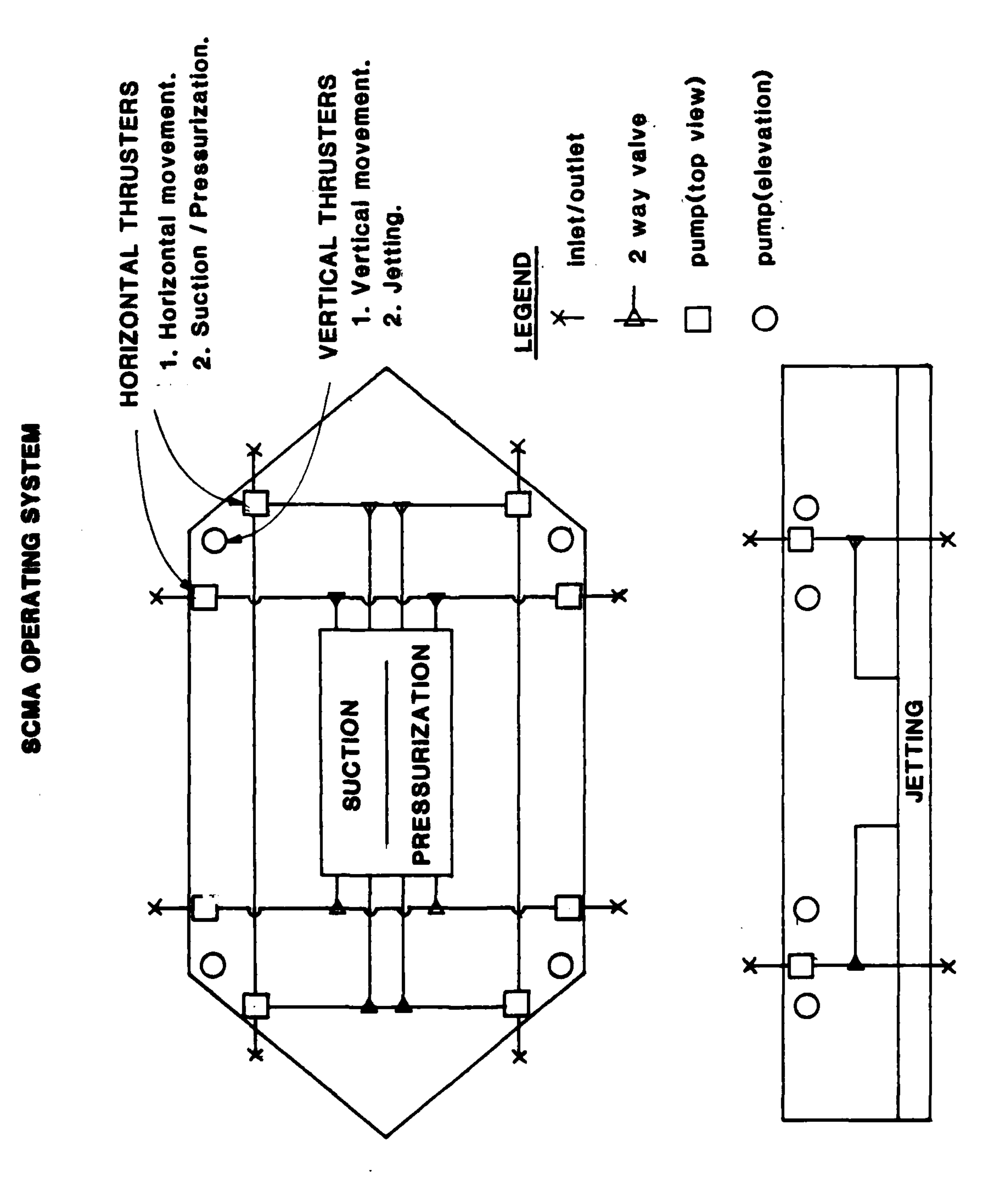
PROJECT:	NAVY PIER CONCEPTS
ITEM:	INSTANT ANCHOR FOR EXP. PIER
DESIGN:	SCMA OPERATING SYSTEM
DATE:	

SHEET: Fig 11
OF
REVISION:



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PROJECT: NAVY PIER CONCEPTS
ITEM: INSTANT ANCHOR FOR EXP. PIER
DESIGN: MOORING OPERATION
DATE:

SHEET: F-4 12
OF
REVISION:

MOORING OPERATION

SCMA is lowered from stern
and maneuvered to predetermined position.

SCMA embeddment
operation to required depth.

Release messenger line
to surface by float to pick up mooring line.

Winch messenger line and mooring line to SCMA.
Connect anchor line to anchor joint by robot arm.

Connect sinkers (weights) to mooring line and launch.

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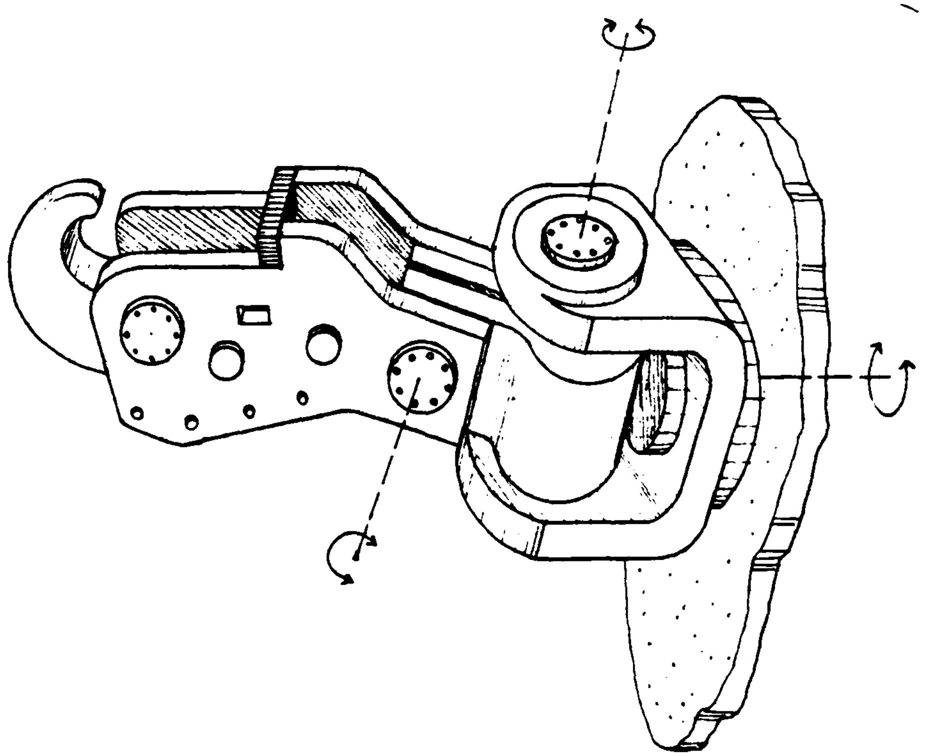
PROJECT: NAVY PIER CONCEPTS	SHEET: Fig 13
ITEM: INSTANT ANCHOR FOR EXP. PIER	OF
DESIGN: UNIVERSAL SWIVEL JOINT	REVISION:
DATE:	

UNIVERSAL SWIVEL JOINT



1" = 40" Appx.

APPENDIX A

Single Point Mooring Analysis and Behavior.

TY/IN International Structural Engineering, 315 Bay St., San Francisco, Ca. 94133	PROJECT: Navy Pier Concepts	SHEET: 4-1
	ITEM: Instant Anchor for Exp. Pier	OF
	DESIGN: Mooring Analysis.	REVISION:
	DATE: 9/83 HN	

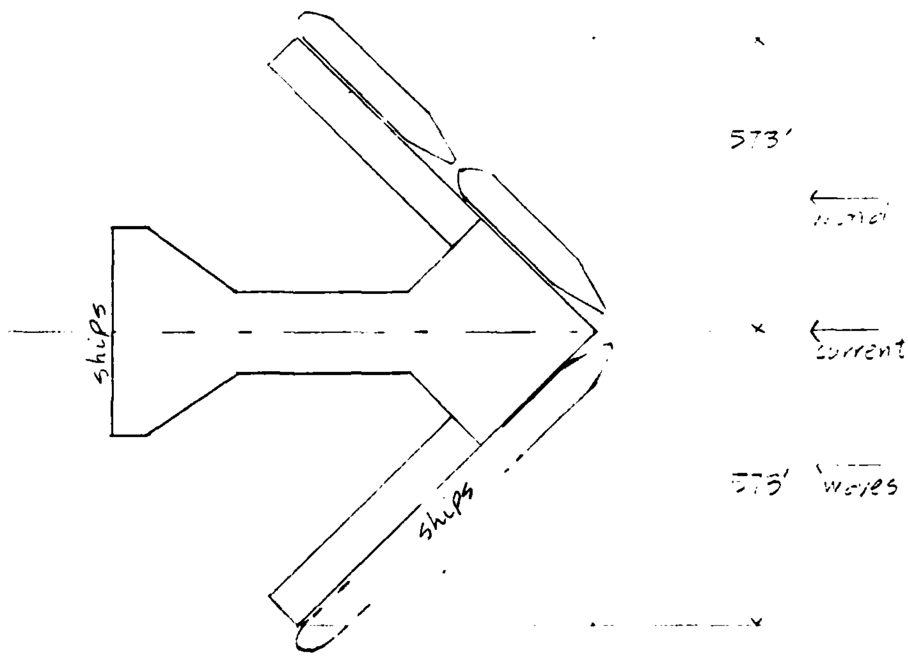
Mooring Forces:

The Expeditionary Pier has been designed for sea state 6. This condition is very severe and is not expected to be in effect when the Pier is in the servicing mode.

Environmental conditions for moored state are as follows:

Max wave height = 3 Ft.
Wind velocity = 13 knots (22.4 f/s)
Current velocity = 1 Knot
wave Period = 6 sec

Approximate Mooring Forces:



Assume 8 CCD--- Type ships are berthed at one time. Draft = 25'.

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PROJECT:	Navy Pier Concepts
ITEM:	Instant Anchor for Exp. Pier.
DESIGN:	Mooring Analysis
DATE:	2/83 [illegible]

SHEET: A-[illegible]
OF
REVISION:

Wave Forces:

Appx estimation of wave forces by TM 26 eqn. 25

$R = 57 A^2 B \sin^2\alpha$
$R = 57 \times 3^2 \times (573 \times 2) \sin^2 45^\circ$
$R = 294$ kip OR 300 kips.

Wind forces:

(Projected side area of ship)
$F_w = \frac{1}{2} \rho C A_p V^2 \cos^2\alpha$
$F_w = \frac{1}{2} \times 0.00237 \times 1.0 \times (4 \times 25000) \times 30.4^2 \; (\cos^2 45)$
$F_w =$ 55 kips.

Surge :

$F_s \simeq 0.33 F_w = 0.33 \times 30 = 10$ kips

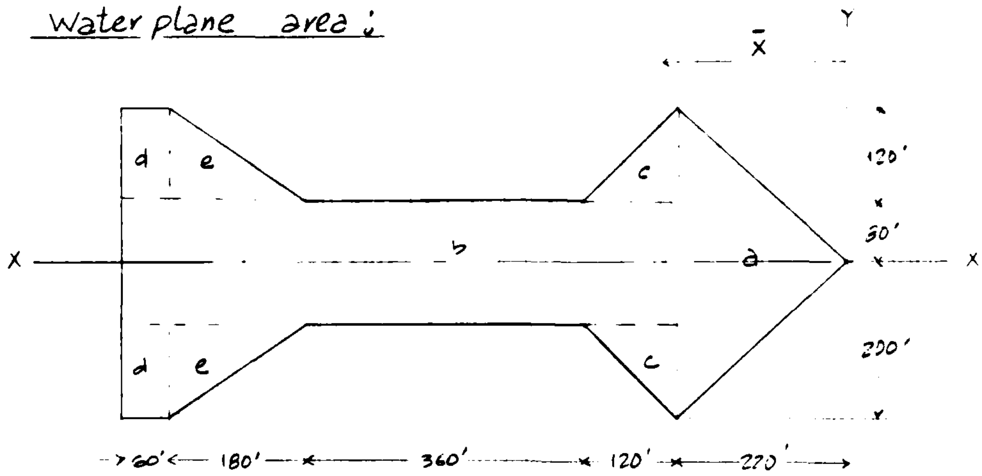
Current: (@ 1 knot or 1.69 fps)
$F_{CD} = \frac{1}{2} \rho C_D A V^2$
$F_{CD} = \frac{1}{2} \times 1.99 \times 1.2 \times (573 \times 2 \times 25) \times 1.69^2 =$ [illegible] kips
$F_{CS} = \frac{1}{2} \rho C_S A_S V^2$
$F_{CS} = \frac{1}{2} \times 1.99 \times 0.01 \times 580900 \times 1.69^2 = 16.5$ kips

∴ Total horizontal force on the pier

$F \simeq 300 + 55 + 10 + 136 + 16.5 \simeq \underline{526}$ kips*

This force is based on the assumption that the wind, current and waves all load the pier in [illegible] same direction; as shown in the figure above. The environmental conditions defined above, may not be exceeded during the servicing mode. In case of severe weather the pier is to be towed out to sea or secured by an appropriate mooring system. The stiff-leg or the special mooring and anchor system will be designed based on the calculated force. OR, a system should be designed for a wave ht of six ft., plus a combination of wind & current [illegible] [illegible] total force of 1000 k on the Exp. Pier.

Water plane area :



	area FT^2	X FT	Y FT	AX FT^2	AX^2 FT^4	I_{OY} FT^4	AY^2 FT^4	I_{OX} FT^4
a	44000	147	0	6468000	950.8×10^6	118.31×10^6	0	233.33×10^6
b	115200	580	0	66816000	38.75×10^9	4.977×10^9	0	245.76×10^6
c	14400	260	120	3744000	973.4×10^6	11.52×10^6	207.36×10^6	11.52×10^6
d	14400	910	140	13104000	11.92×10^9	4.32×10^6	282.24×10^6	17.28×10^6
e	21600	820	120	17712000	14.52×10^9	38.88×10^6	311.04×10^6	17.28×10^6
Σ	209600			107844000	67.118×10^9	5.15×10^9	800.64×10^6	594.17×10^6

$$\bar{X} = \frac{107844000}{209600} = 514.5 \text{ FT.}$$

$$I_{XX} = I_{OX} + AY^2 = 594.17 \times 10^6 + 800.64 \times 10^6$$

$$I_{XX} = 1394 \times 10^6 \ \text{FT}^4$$

$$I_{YY} = I_{OY} + AX^2 - A\bar{X}^2$$

$$I_{YY} = 5.15 \times 10^9 + 67.118 \times 10^9 - 209600 \times 514.5^2$$

$$I_{YY} = 16.785 \times 10^9 \ \text{FT}^4$$

TY IN INTERNATIONAL
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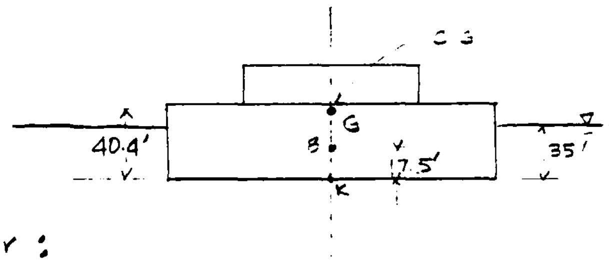
PROJECT: Navy Pier Concepts
ITEM: Instant Anchor for Exp. Pier
DESIGN: Metacentric Height
DATE:

SHEET: A-4
OF
REVISION:

(From Report No. 1/83)

$KG = 40.4$ FT.



Transverse Metacenter:

$$GM_T = \frac{1394.0 \times 10^6}{(209600 \times 35)} - (40.4 - 35/2)$$

$$GM_T = \underline{167 \text{ FT.}}$$

$$r_x = (1394 \times 10^6 / 209600)^{1/2} = 81.6 \text{ FT}$$

Longitudinal Metacenter:

$$GM_L = \frac{16.785 \times 10^9}{(209600 \times 35)} - (40.4 - 35/2)$$

$$GM_L = \underline{2265 \text{ FT}}$$

$$r_Y = (16.785 \times 10^9 / 209600)^{1/2} = 283 \text{ FT.}$$

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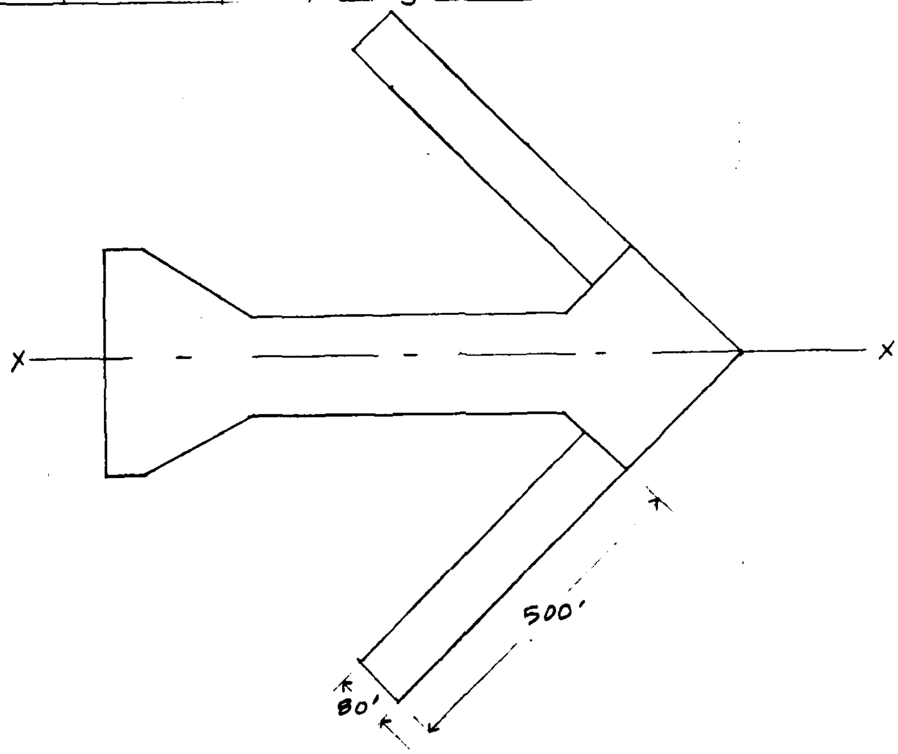
PROJECT: Navy Pier Concepts
ITEM: Instant Anchor for Exp. Pier
DESIGN: Waterplane Properties
DATE:

SHEET: A-5
OF
REVISION:

Waterplane Props w/ Fingers



$A_P = 209600 + (500 \times 80 \times 2) = 289600 \text{ FT}^2$

$I_{xx} = 1394 \times 10^6 + 2(80 \times 500 \times 377^2) + 428028000$

$I_{xx} = 1.3192 \times 10^{10} \text{ FT}^4$

Radius of gyration $= \left(\frac{1.3192 \times 10^{10}}{289600}\right)^{1/2} = 213$ FT.

Roll rad of gyr is comparable to above value since mass is appx. proportional to the area.

For typ barge type vessels:

$R_{ROLL} = 0.32\,B \simeq 213$ FT

$R_{PITCH} = 0.29\,L = 0.29 \times 940 \simeq 275$ FT

$R_{YAW} = 0.29\,L \simeq 275$ FT.

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PROJECT: Navy Pier Concepts	SHEET: A-6
ITEM: Instant Anchor for Exp. Pier	OF
DESIGN: Metacentric Height.	REVISION:
DATE:	

(From Report NO 1/83)

KG = 40 FT (From base line)

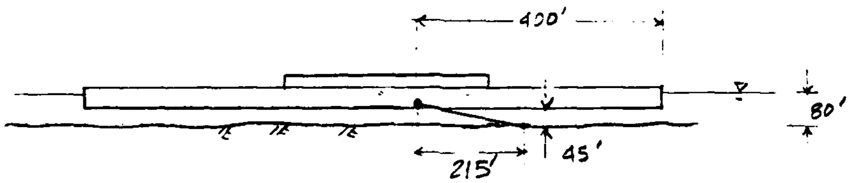
KB = 19.0 FT

$$GM_T = \frac{1.3192 \times 10^{10}}{8456000} - (40 - 19)$$

GM_T = 1540 FT.

MOORING ANALYSIS:

draft = 35'
depth = 80'
stiff leg : Length = 220' ; W = 980 lb/FT. ; A = 288 in^2
$E = 29 \times 10^3$ ksi ; $AE = 8.4 \times 10^9$ lb



Finger Spine Hinge:

$\ell = 0.5'$, $AE = 7.2 \times 10^9$ lbs

Wind Areas: (based on projected area of typ. ship)

Projected area per Ft $= \frac{25000}{500} = 50$ Ft^2/ft

Spine: $A_X = 50 \times 400 = 20{,}000$ Ft^2
$A_Y = 50 \times 940 = 47000$ Ft^2

Fingers: $A_X = 50 \times 80 = 4000$ Ft^2
$A_Y = 50 \times 500 = 25000$ Ft^2

THEORY

The forces imposed on the mooring system are caused by wind, current and waves. A single-point mooring system will not prevent the vessel from changing its heading, but prevents it from drifting. By heading the sea, the vessel will resist the least forces.

The wind and current forces mainly arise due to pressure drag and viscous drag. These forces are dependent on the shape and size of the vessel, and the environmental conditions, several empirical techniques are available to estimate these forces. OSCAR uses a similar approach.

The forces on a moored body can be conisdered to consist of two components. One is the non-linear contribution, which comprises wind, current and a portion of the wave drift force. The non-linear forces are constant in nature. Non-linear contribution of the wave forces is not very large in most cases. On the other hand, the linear contribution of the wave drift force varies with the encounter frequency and is quite large for moored bodies. Since the linear contribution is a function of the wave height over a wave cycle, it will produce a zero net force, while the non-linear contribution will yield a mean force in the direction of wave propagation. In other words, the magnitude of the linear force oscillates about a mean value which is the non-linear contribution. Thus, a new equilibrium position can be calculated statically based on the non-linear forces.

The effects of the direct wave motions can be either calculated based on specified Response Amplitude Operators (RAO's) for the vessel or a frequency domain analysis can be performed of the direct wave induced motion considering the stiffness of the mooring system in the equilibrium configuration. For the "stiff-leg" mooring system, the linear wave forces described above are expected to be very significant since the stiff-leg member will tend to resist any sudden motions in a rigid manner.

ANALYTICAL MODEL

OSCAR provides two options by which the hydrodynamic forces can be calculated. One is the strip theory, and the other the *three dimensional wave diffraction* theory.

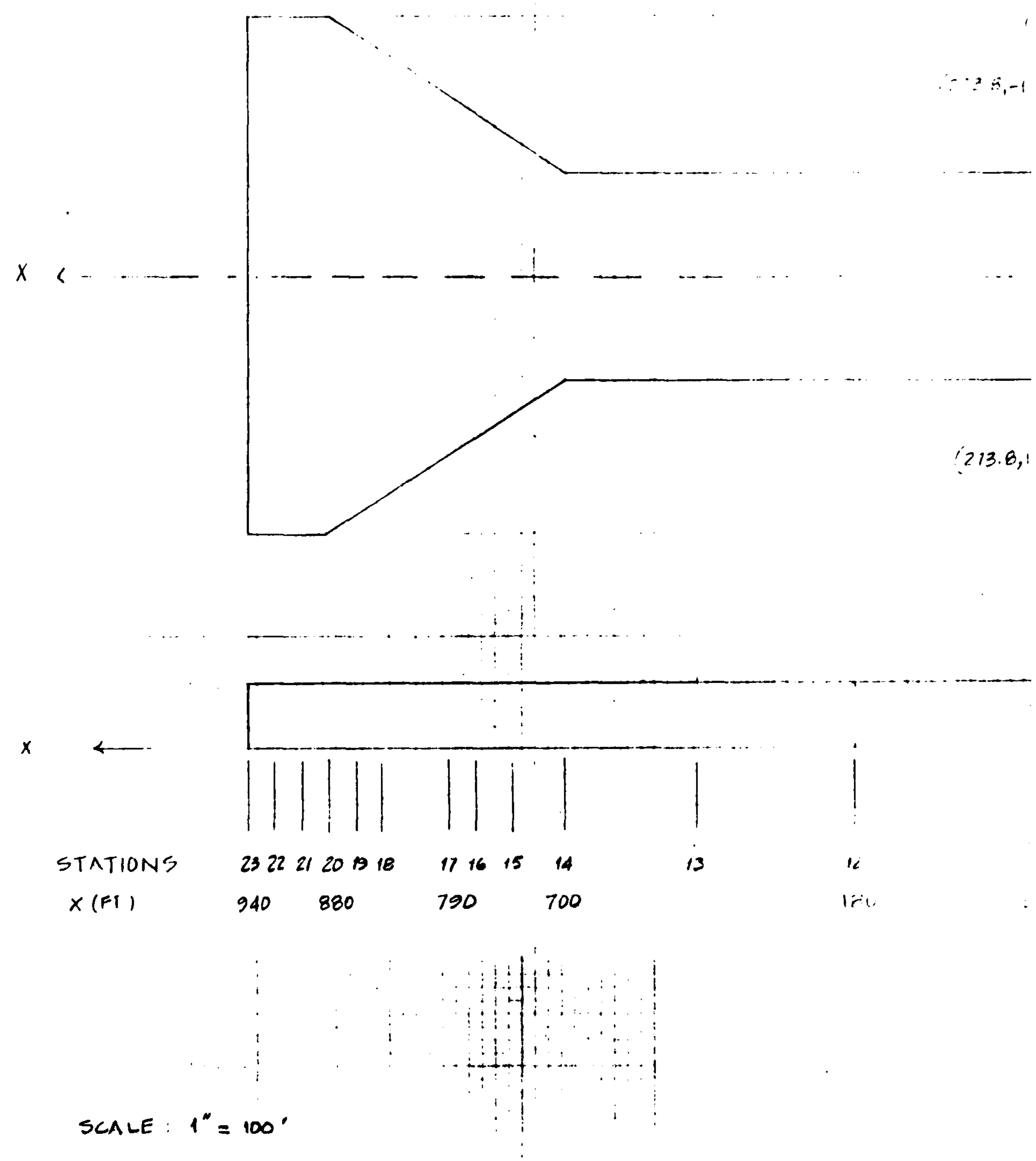
The strip theory was used to analyze the expeditionary pier. In the service mode, the expeditionary pier has the finger or the wing piers fully extended (Fig. 1). In essence, there are three vessels interacting with each other, along with the moored ships. OSCAR can only incorporate two vessels at one time in an analysis. This limitation was overcome by modelling the wings of an integral part of the spine pier. Since the pier with or without the wings has very high radii of gyration in roll and pitch, their approximation will not greatly affect the computed motions of the vessel for head seas. This is illustrated by a comparison of RAO's of a model with large radii of gyration and a model that represents the radii of gyration of the spine pier alone. See pp. A-12 - A-13, Appendix A.

Another limitation that ensues by using the above model is in the computation of the non-linear component of drift forces. In order to calculate these, OSCAR makes certain assumptions that may be applicable to regular vessels, but may not be apt for a large, irregular waterplane area of the model described for the expeditionary pier. For instance, OSCAR makes certain generalities of the vessel shape and size relative to the wave length, which imply erroneous effects of wave diffraction and generation.

On the other hand, the linear component or the oscillatory component is not as complex to calculate as the non-linear component. This is a function of wave velocity, height, angle, etc.; the motion history and the wave diffraction potentials are not involved in the linear motions.

Since the non-linear drift forces will not be very significant in the behavior of the stiff-leg, these can be estimated by other means conservatively. The approach will be to estimate the forces that are "static" in nature (wind, current and non-linear effect of wave drift) and impose these on the system at the corresponding equilibrium position, fix the system, and impose the irregular sea condition of interest and find the linear motions and the resulting forces on the stiff-leg. The motions and accelerations yielded by this calculation can also help in selecting (designing) the equipment that may be used on the expeditionary pier.

The results and pertinent output are included in Appendix A.



SCALE : 1" = 100'

PROJECT Nº

DESIGN

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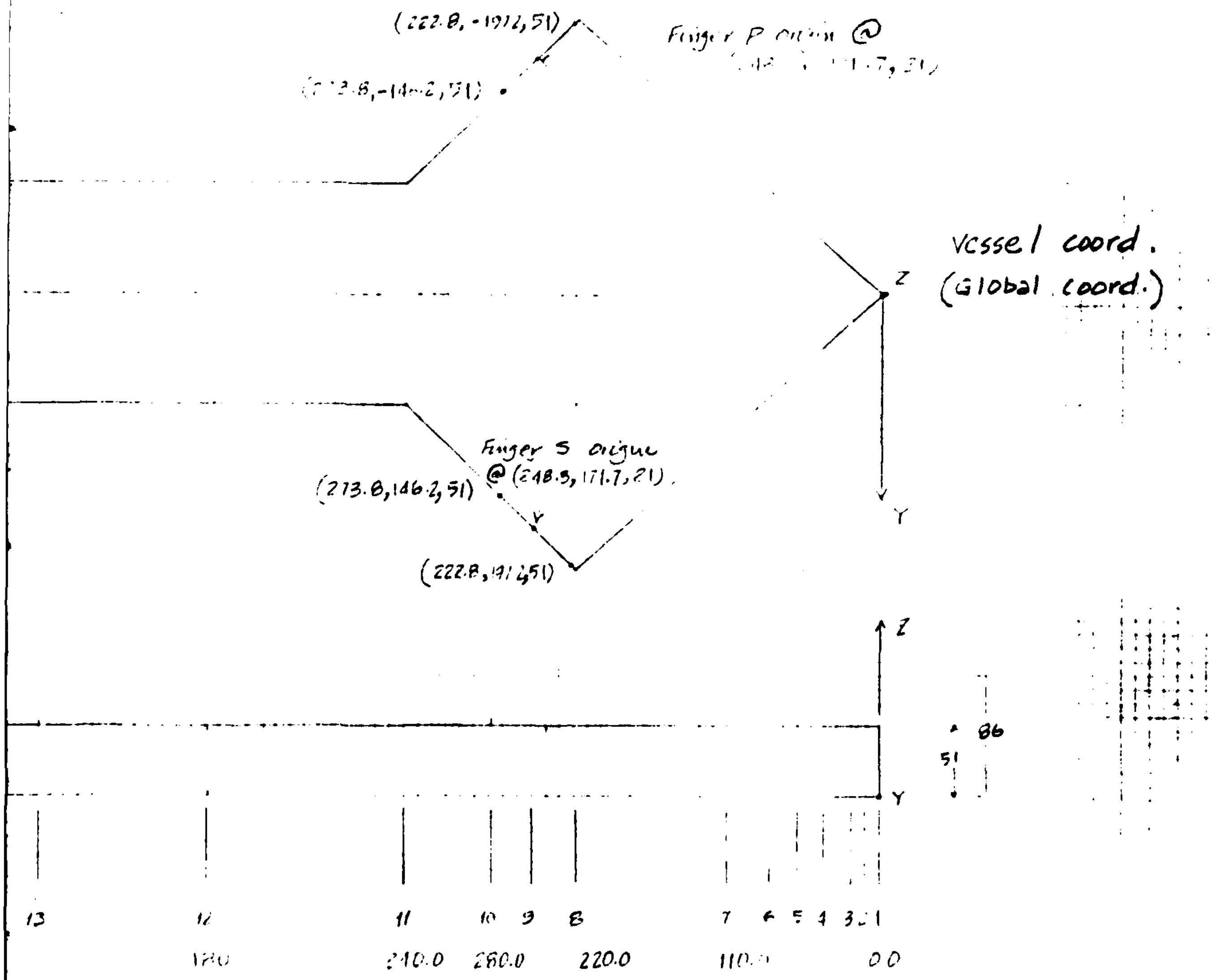

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SHEET TITLE: MOORING ANALYSIS MODEL (OSCAR)

PROJECT: Instant Anchor for Expeditionary Pier

SHEET NO

2

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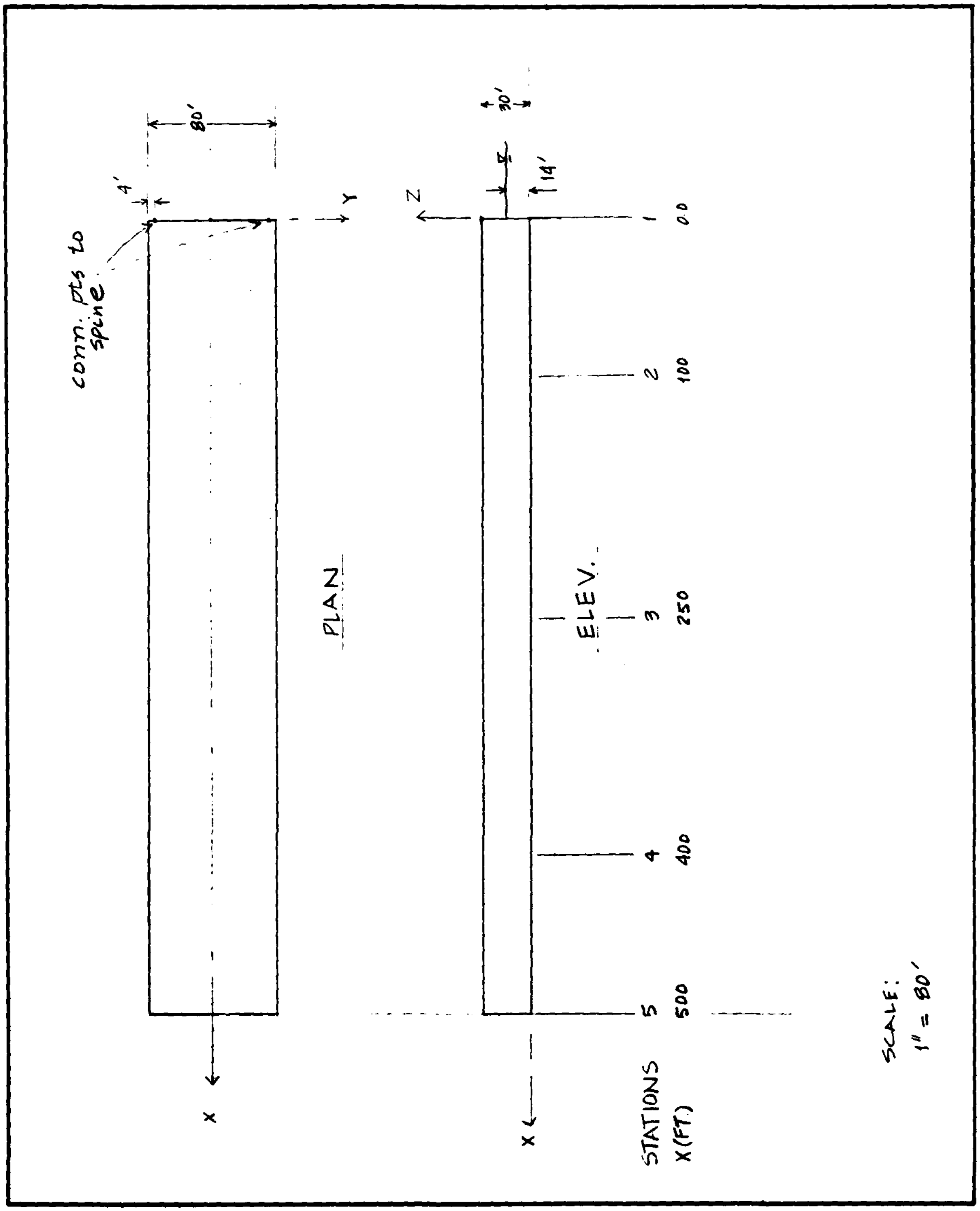
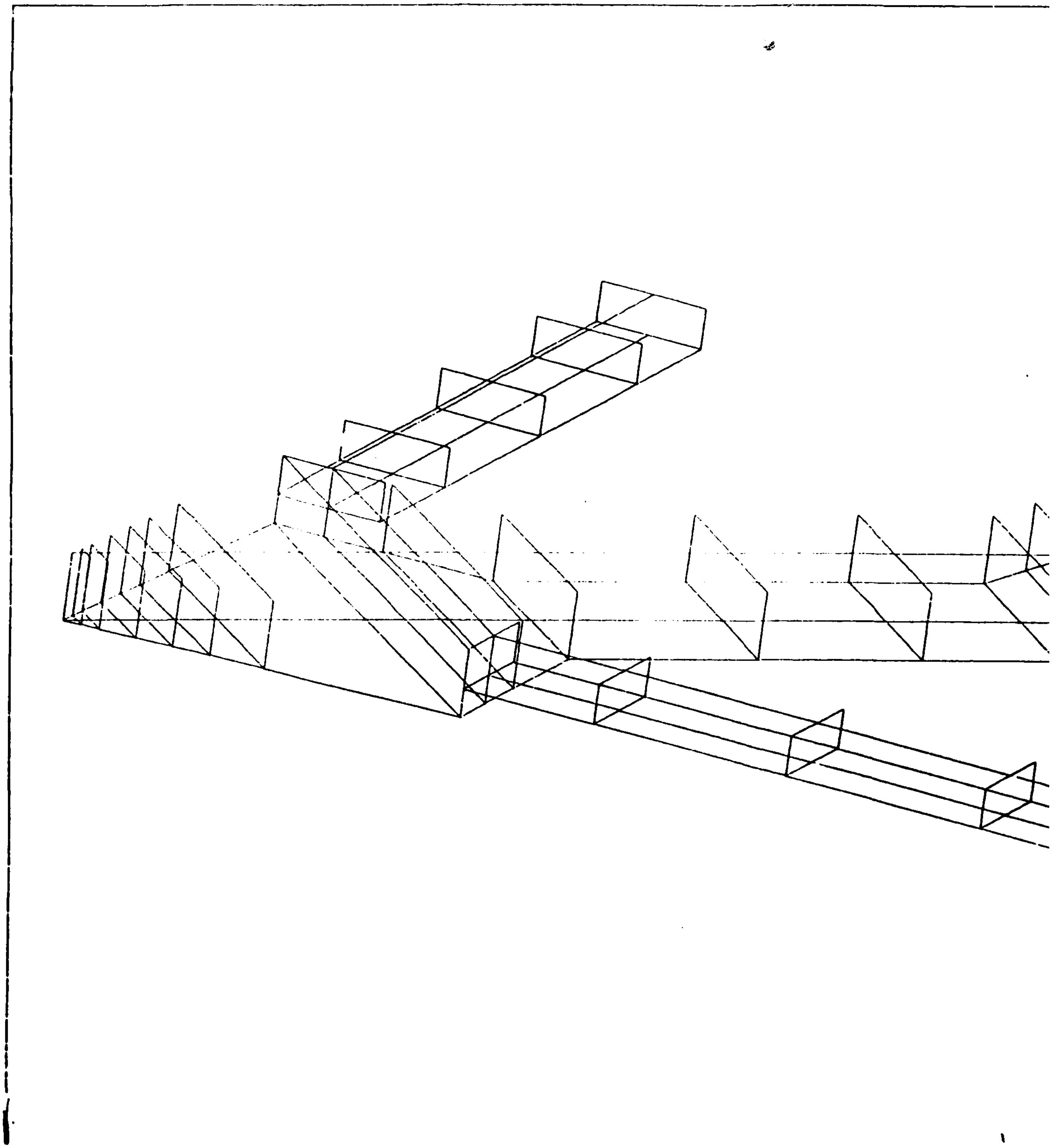
PROJECT:	Navy Pier Concepts
ITEM:	Instant Anchor for Exp. Pier
DESIGN:	Analytical Model.
DATE:	

SHEET: A - 9
OF
REVISION:



Analytical Model (OSCAR)



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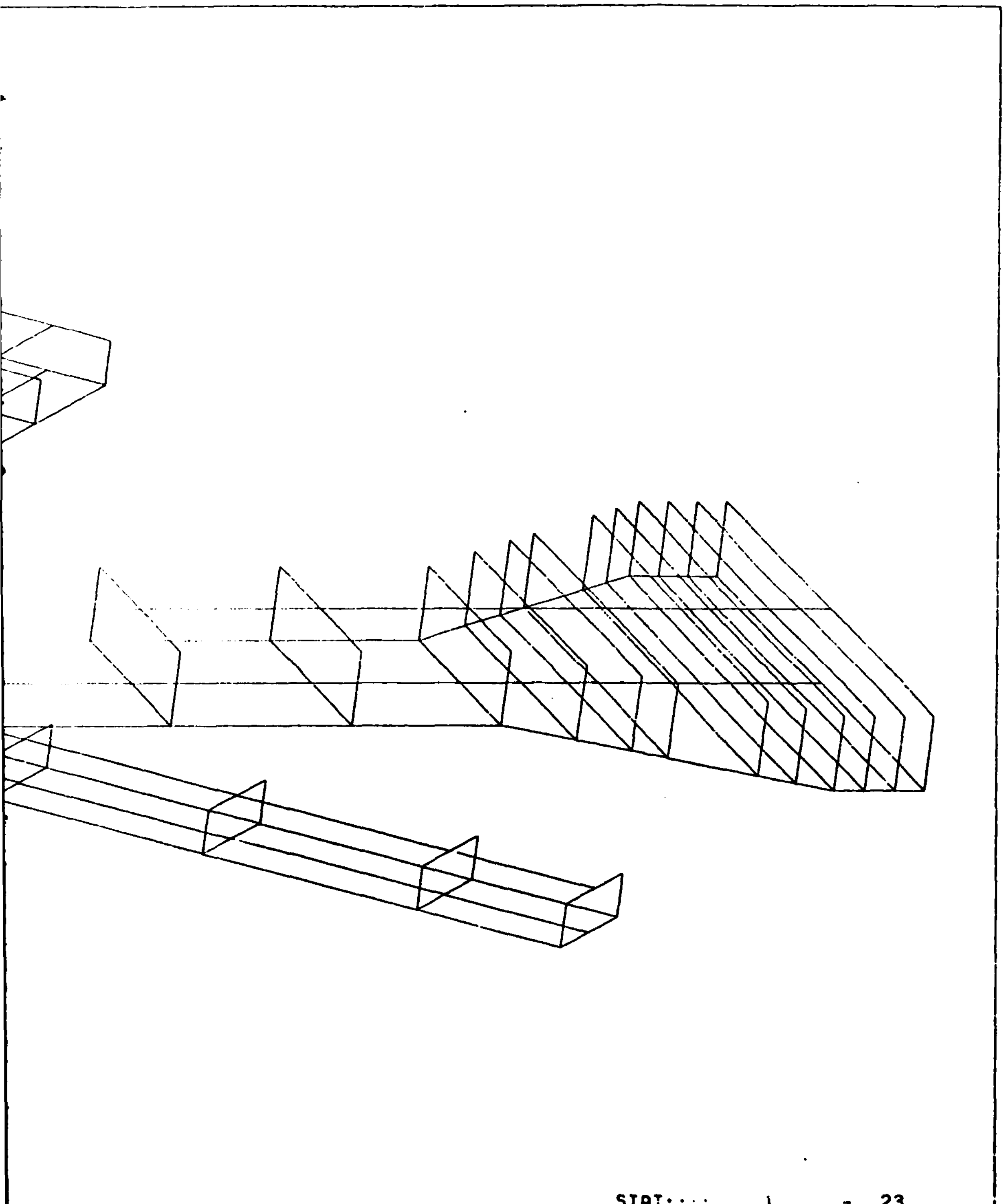

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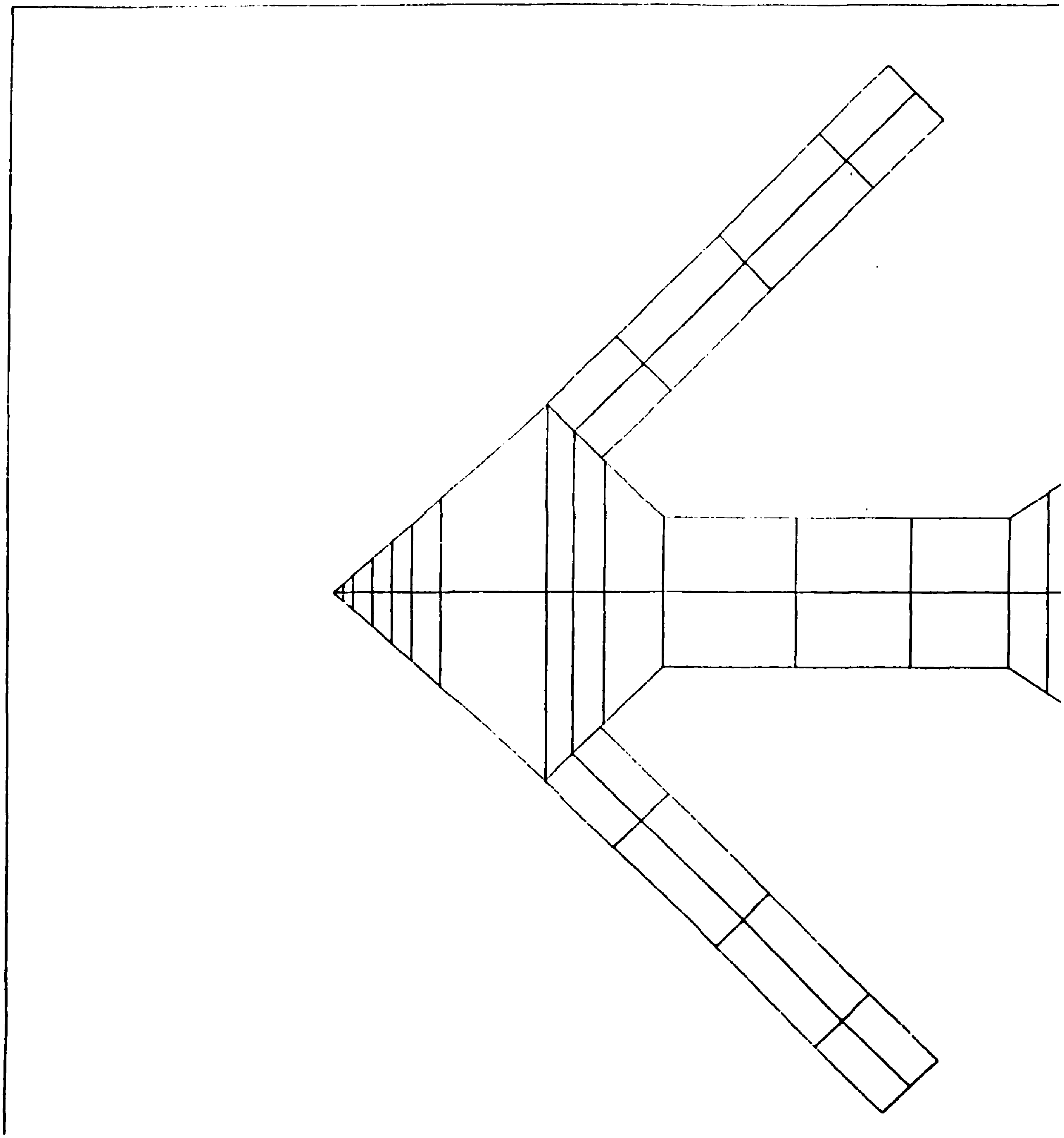
Analytical Model (OSCAR)



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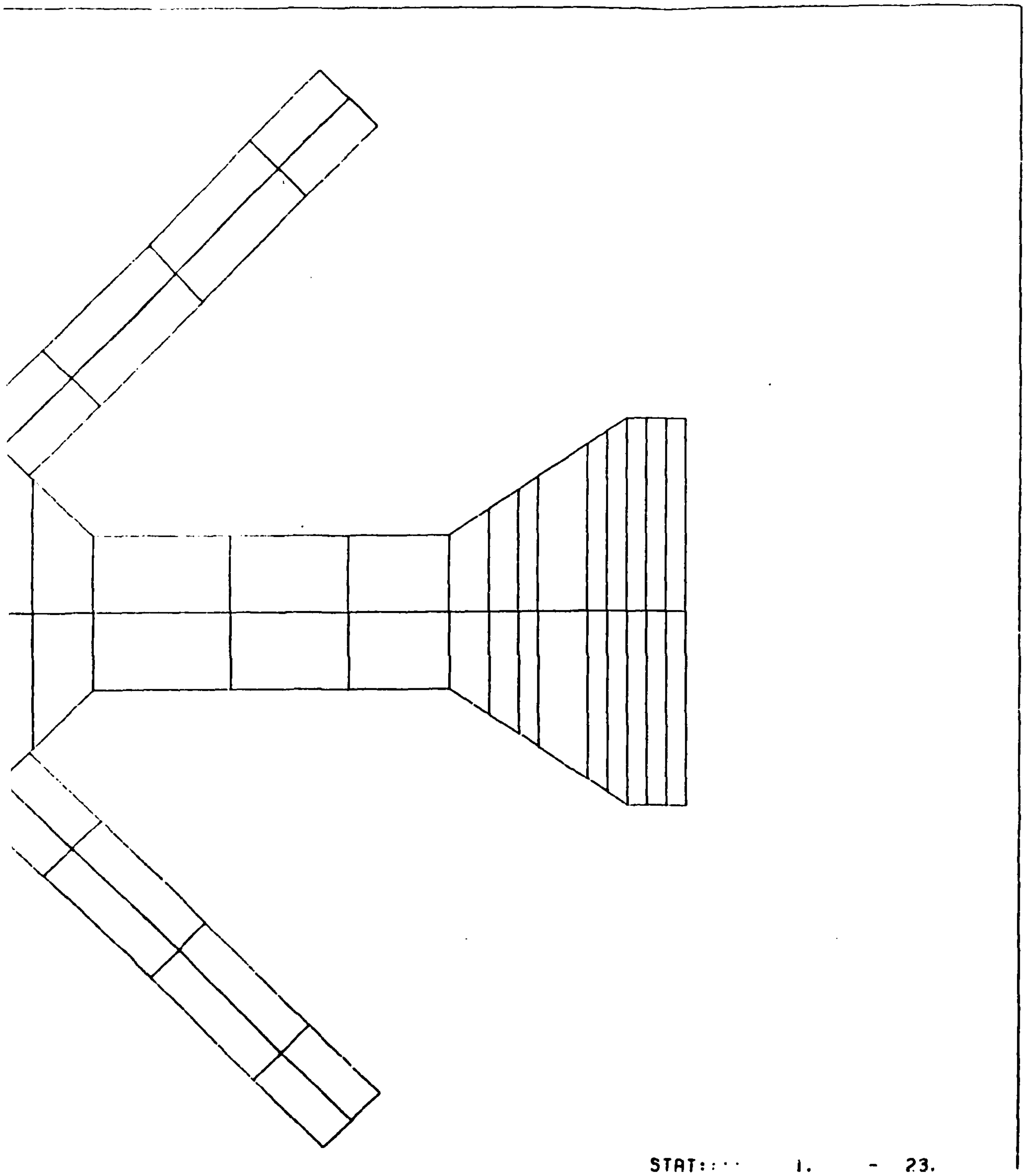

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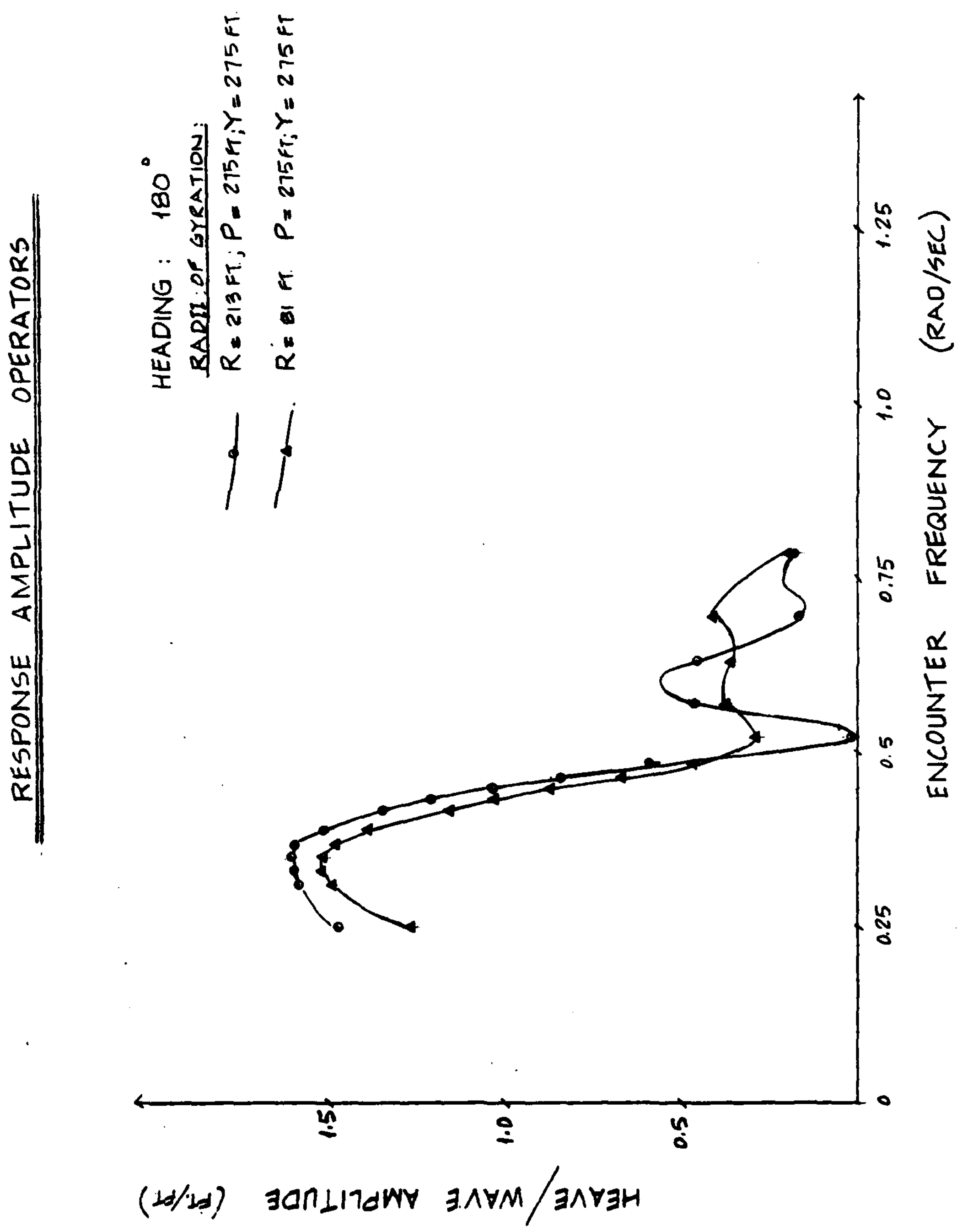
PROJECT:	NAVY PIER CONCEPTS
ITEM:	FREE FLOATING
DESIGN:	HEAVE RAO
DATE:	11/83 JHN

SHEET: A-12
OF:
REVISION:



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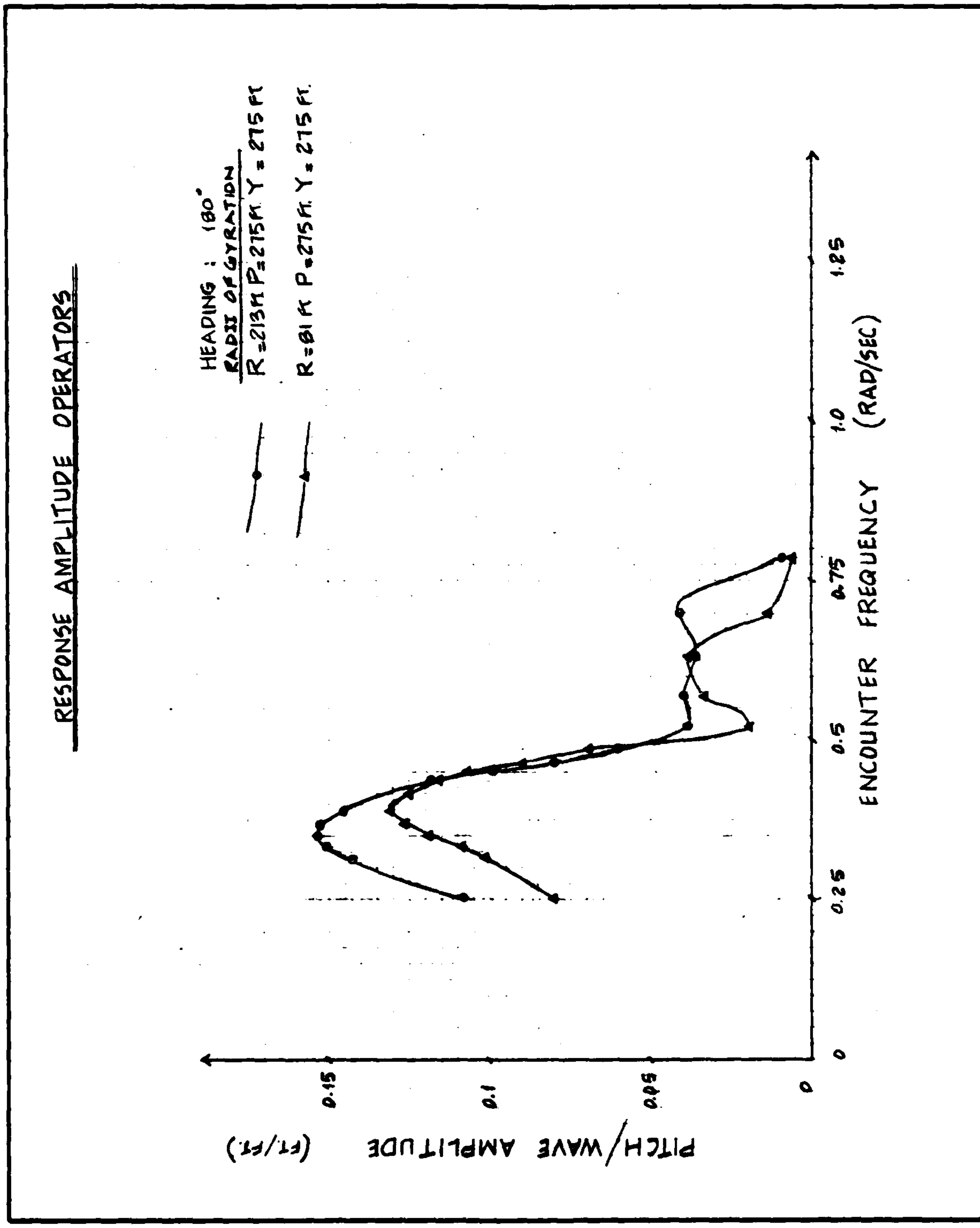
PROJECT:	NAVY PIER CONCEPTS
ITEM:	FREE FLOATING
DESIGN:	PITCH RAO
DATE:	11/83 HN

SHEET: A-13
OF
REVISION:



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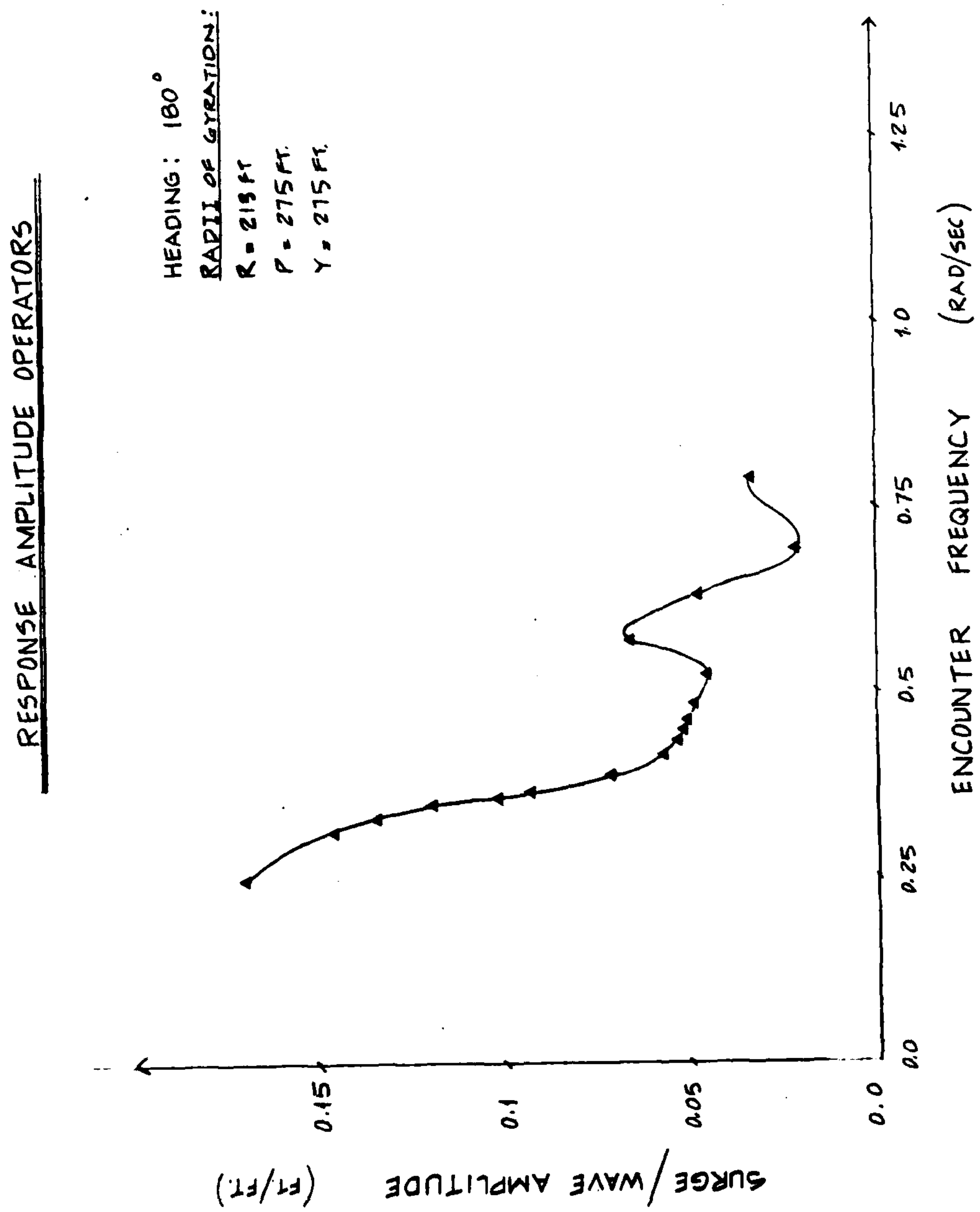
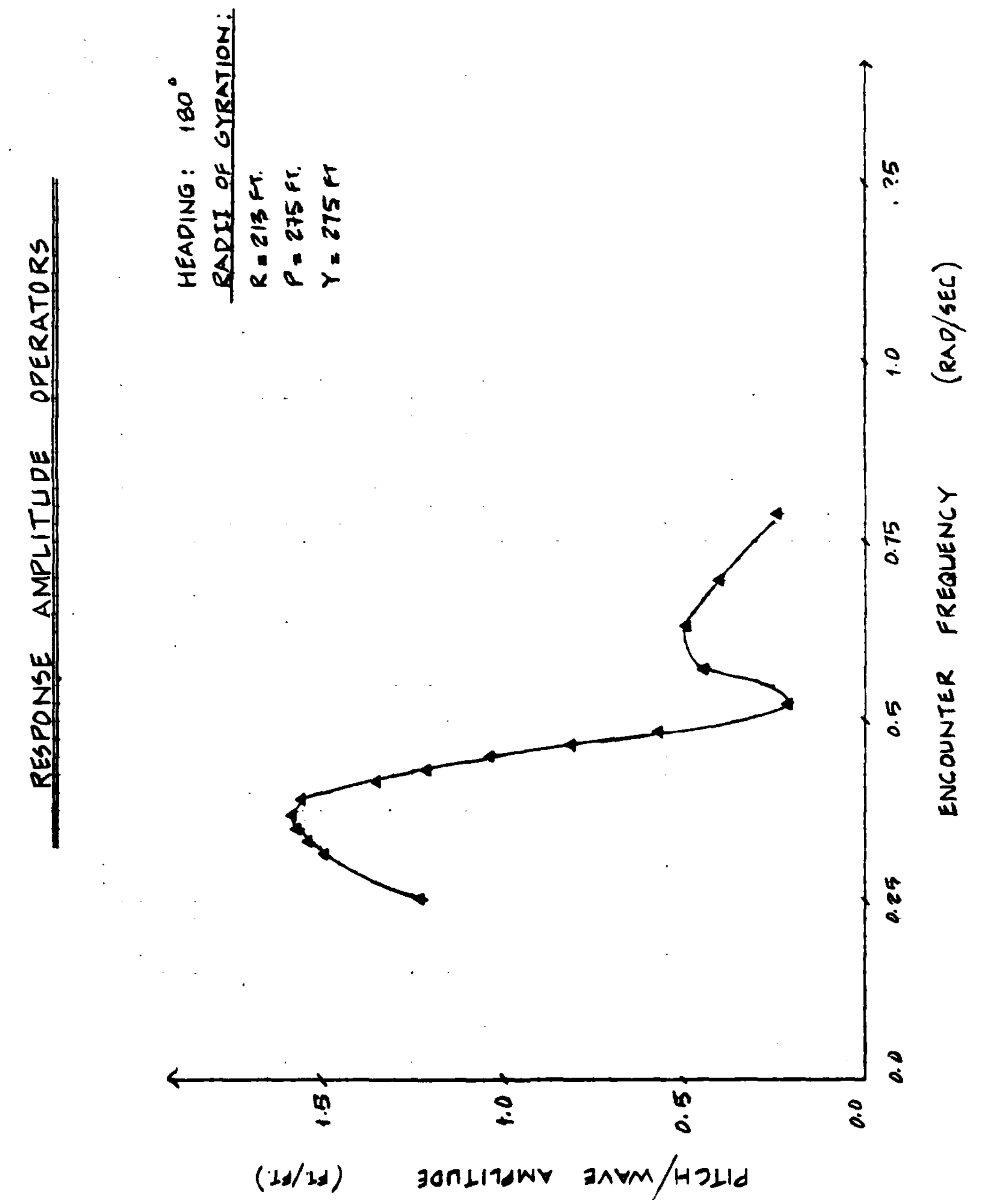
PROJECT:	NAVY PIER CONCEPTS
ITEM:	MOORING
DESIGN:	SURGE RAO
DATE:	

SHEET: A-13
OF
REVISION:



TYIN INTERNATIONAL STRUCTURAL ENGINEERING 315 Bay St., San Francisco, Ca. 94133	PROJECT: NAVY PIER CONCEPTS ITEM: MOORING DESIGN: HEAVE RAO DATE: 11/83 HN	SHEET: A-14 OF REVISION:



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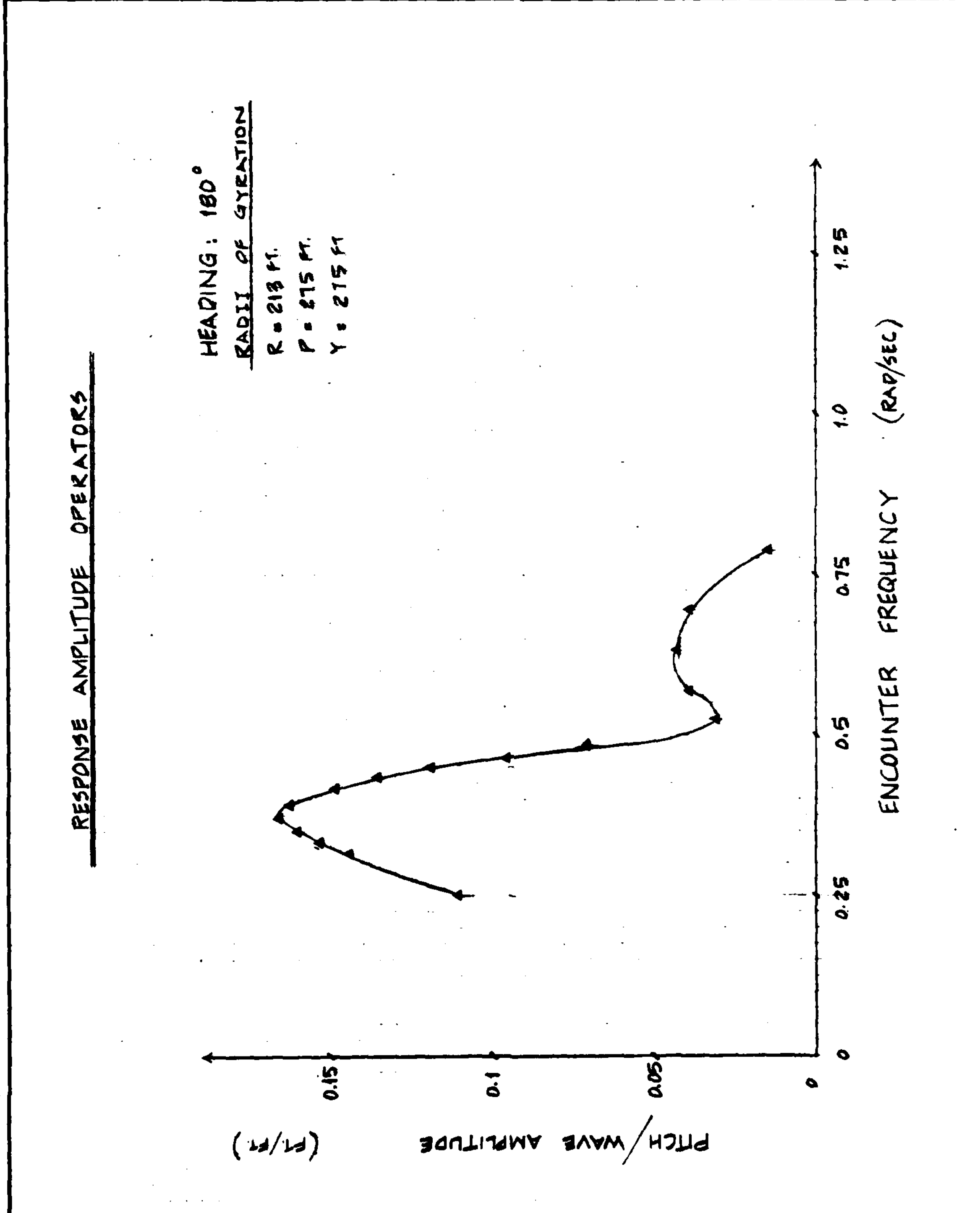

EX. PIER W/ WING PI... (FREE FLOATING)

RADII OF GYRATION: ROLL = 81 FT.
PITCH = 275 FT.
YAW = 275 FT.

S T A T I S T I C S O F M O T I O N S I N I R

OF BODY EXPIER

S E A S P E C T R U M

ISSC --- SIGNIFICANT HEIGHT = 6.0 FEET   MEAN P

S I N G L E A M P L I T U D E M O

	SURGE -(FEET)-	SWAY -(FEET)-	HEAVE -(FEET)-
ROOT MEAN SQUARE	.427	.207	.234
AVE OF 1/3 HIGHEST	.853	.413	.469
AVE OF 1/10 HIGHEST	1.088	.527	.598
AVE OF 1/100 HIGHEST	1.425	.690	.783

S T A T I S T I C S O F A C C E L E R A T I O N I N I

S I N G L E A M P L I T U D E

	SURGE (FEET /SEC**2)	SWAY (FEET /SEC**2)	HEAVE (FEET /SEC**2)
ROOT MEAN SQUARE	.231	.166	.136
AVE OF 1/3 HIGHEST	.463	.332	.272
AVE OF 1/10 HIGHEST	.590	.423	.346
AVE OF 1/100 HIGHEST	.773	.554	.454

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O T I O N S   I N   I R R E G U L A R   S E A S

OF BODY EXPIER

A   S P E C T R U M

= 6.0 FEET   MEAN PERIOD = 6.0 SECONDS

A M P L I T U D E   M O T I O N S

SWAY -(FEET)-	HEAVE -(FEET)-	ROLL --(DEG)--	PITCH --(DEG)--	YAW --(DEG)--
.207	.234	.007	.018	.009
.413	.469	.013	.036	.018
.527	.598	.017	.046	.023
.670	.783	.023	.060	.030

L R A T I O N   I N   I R R E G U L A R   S E A S

G L E   A M P L I T U D E S

*2)	HEAVE (FEET /SEC**2)	ROLL (DEG/SEC**2)	PITCH (DEG/SEC**2)	YAW (DEG/SEC**2)
	.136	.006	.010	.006
	.272	.012	.020	.012
	.346	.015	.025	.016
	.454	.020	.033	.021

Nº	REVISION	DATE

Issued For	Date	By

SHEET TITLE: OSCAR OUTPUT

PROJECT: Navy Pier Concepts

SHEET Nº A-16

EX. PIER W/ WING PIERS : (FREE FLOATING)

RADII OF GYRATION: ROLL = 213 FT.
PITCH = 275 FT
YAW = 275 FT.

STATISTICS OF MOTIONS IN IRRE

UF BODY EXPIER

SEA SPECTRUM

ISSC --- SIGNIFICANT HEIGHT = 6.0 FEET MEAN PERIOD

SINGLE AMPLITUDE MOTIO

	SURGE -(FEET)-	SWAY -(FEET)-	HEAVE -(FEET)-	RO --(D
ROOT MEAN SQUARE	.084	.112	.254	
AVE OF 1/3 HIGHEST	.169	.225	.509	
AVE OF 1/10 HIGHEST	.215	.287	.648	
AVE OF 1/100 HIGHEST	.282	.375	.849	

STATISTICS OF ACCELERATION IN IRR

SINGLE AMPLITUDES

	SURGE (FEET /SEC**2)	SWAY (FEET /SEC**2)	HEAVE (FEET /SEC**2)	R (DEG
ROOT MEAN SQUARE	.041	.081	.158	
AVE OF 1/3 HIGHEST	.081	.163	.316	
AVE OF 1/10 HIGHEST	.104	.207	.403	
AVE OF 1/100 HIGHEST	.136	.271	.527	

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PROJECT Nº

NG)

MOTIONS IN IRREGULAR SEAS

UF BODY EXPIER

A SPECTRUM

T = 6.0 FEET MEAN PERIOD = 6.0 SECONDS

AMPLITUDE MOTIONS

SWAY -(FEET)-	HEAVE -(FEET)-	ROLL --(DEG)--	PITCH --(DEG)--	YAW --(DEG)--
.112	.254	.031	.023	.009
.225	.509	.061	.046	.018
.287	.648	.078	.059	.023
.375	.849	.102	.078	.030

ERATION IN IRREGULAR SEAS

GLE AMPLITUDES

*2)	HEAVE (FEET /SEC**2)	ROLL (DEG/SEC**2)	PITCH (DEG/SEC**2)	YAW (DEG/SEC**2)
	.158	.015	.013	.006
	.316	.030	.026	.012
	.403	.038	.033	.016
	.527	.050	.044	.021

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REVISION | DATE

SHEET TITLE: OSCAR Output

PROJECT: Navy Pier Concepts

SHEET Nº A-17

2

EX. PIER W/ WING PIERS (MOORED)

S T A T I S T I C S   O F   M O T I O N S   I N   I R R E

OF BODY EXPIER

S E A   S P E C T R U M

ISSC --- SIGNIFICANT HEIGHT = 6.0 FEET   MEAN PERIC

S I N G L E   A M P L I T U D E   M O T I

	SURGE -(FEET)-	SWAY -(FEET)-	HEAVE -(FEET)-	R --(
ROOT MEAN SQUARE	.058	.000	.349	
AVE OF 1/3 HIGHEST	.116	.000	.699	
AVE OF 1/10 HIGHEST	.148	.000	.891	
AVE OF 1/100 HIGHEST	.194	.000	1.167	

S T A T I S T I C S   O F   A C C E L E R A T I O N   I N   I R R

S I N G L E   A M P L I T U D E S

	SURGE (FEET /SEC**2)	SWAY (FEET /SEC**2)	HEAVE (FEET /SEC**2)	(D
ROOT MEAN SQUARE	.094	.000	.209	
AVE OF 1/3 HIGHEST	.188	.000	.417	
AVE OF 1/10 HIGHEST	.240	.000	.532	
AVE OF 1/100 HIGHEST	.314	.000	.697	

M O T I O N S   I N   I R R E G U L A R   S E A S

OF BUOY EXPIER

E A   S P E C T R U M

GHT = 6.0 FEET   MEAN PERIOD = 6.0 SECONDS

A M P L I T U D E   M O T I O N S

	SWAY -(FEET)-	HEAVE -(FEET)-	ROLL --(DEG)--	PITCH --(DEG)--	YAW --(DEG)--
3	.000	.349	.000	.029	.000
5	.000	.699	.000	.059	.000
8	.000	.891	.000	.075	.000
4	.000	1.167	.000	.098	.000

L E R A T I O N   I N   I R R E G U L A R   S E A S

N G L E   A M P L I T U D E S

C**2)	HEAVE (FEET /SEC**2)	ROLL (DEG/SEC**2)	PITCH (DEG/SEC**2)	YAW (DEG/SEC**2)
0	.209	.000	.017	.000
0	.417	.000	.033	.000
0	.532	.000	.042	.000
0	.697	.000	.055	.000

Issued For	Date	By

Nº | REVISION | DATE

SHEET TITLE: OSCAR OUTPUT

PROJECT: Navy Pier Concept's

SHEET Nº A-18

TYIN INTERNATIONAL STRUCTURAL ENGINEERING 315 Bay St., San Francisco, Ca. 94133	PROJECT: NAVY PIER CONCEPTS	SHEET: A-19
	ITEM: MOORING FORCES	OF
	DESIGN: STATISTICS OF FORCES.	REVISION:
	DATE: 11/83 HN	

EX. PIER W/ WING PIERS; R= 213'; P= 275', Y = 275'.

STATISTICS OF MOORING FORCES:

IN

SEA SPECTRUM

ISSC --- SIGNIFICANT HEIGHT = 6.0 FEET MEAN PERIOD = 6.0 SECONDS

TENSIONS IN KIPS

STATISTICS OF TENSIONS

MEAN	RMS	1/3 HIGHEST	1/10 HIGHEST	1/100 HIGHEST
173923.	176543.	179164.	180605.	182675.

In order to compute the linear component of the wave forces the stiff-leg was given an arbitrary tension of 173923^k. This is shown as the mean force above. For the imposed sea conditions, shown above, the tension for 1/3 highest wave is 179164^k.

∴ Linear component of wave forces:

$$179164^k - 173923^k = \pm 5240^k$$

This force is oscillitory in nature & in one cycle goes from 5240^k Tension to 5240^k compression.

RESULTS

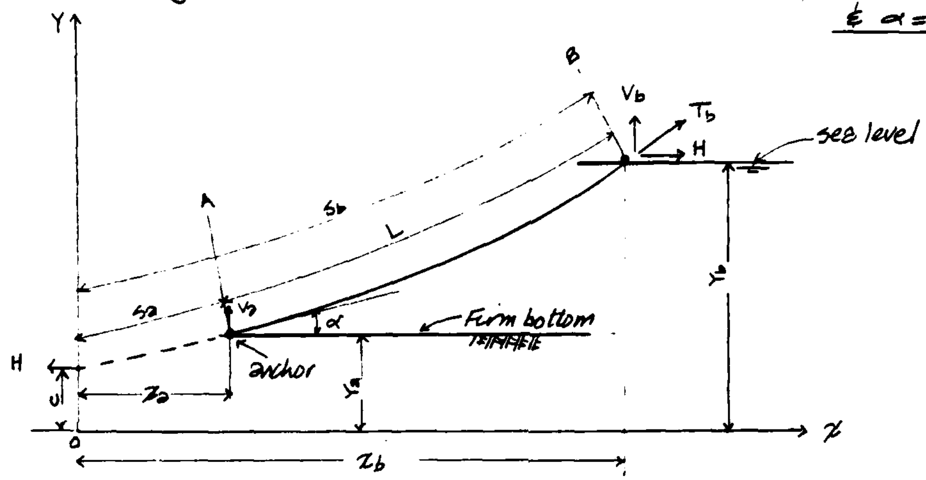
The mooring forces calculated above indicate that the stiff-leg anchor is not feasible. Due to the huge mass and waterplane area of the expeditionary pier, the linear contribution of the wave force is greatly amplified when a stiffness is associated with the vessel. In addition to the tension force, the stiff-leg experiences the same magnitude of compression to complete a cycle corresponding to the wave period.

It is suggested that a mooring line (catenary) should be used to hold the expeditionary pier in position. The catenary line will have to resist the non-linear or the "non-transient" forces caused by wind, current and wave drift. The linear or the transient forces can be absorbed as kinetic energy generated by the movement of the expeditionary pier, limited displacements can be tolerated by the catenary line without developing excessive forces.

TYIN INTERNATIONAL STRUCTURAL ENGINEERING 315 Bay St., San Francisco, Ca. 94133	PROJECT: Navy Pier Concepts ITEM: Instant Anchor for Exp. Pier DESIGN: chain anchor line DATE:	SHEET: A-21 OF REVISION:

Chain anchor line:

check behavior of chain anchor line for a design mooring force of $\underline{2000^k}$ & water depth of $\underline{90 ft.}$
& $\alpha = 15°$



TRY $6\frac{1}{8}''\phi$ chain ; Breaking strength = 3367^k

$w_{air} = 0.335^{k/'}$ or $w_{water} = 0.87 \times 0.335 = 0.291^{k/'}$

$V_a = \tan 15° \times 2000 = 535.9^k$ (for $\alpha = 15°$)

$s_a = \frac{V_a}{w_w} = \frac{535.9}{0.291} = 1841.6'$

$c = H/w_w = 2000/_{0.291} = 6872.9'$

$Y_a = s_a^2 + c^2 = \sqrt{1841.6^2 + 6872.9^2} = 7115.3'$

$Y_b = 7115.3 + 90 = 7205'$

$s_b = Y_b^2 - c^2 = \sqrt{7205^2 - 6872.9^2} = 2163'$

$L = s_b - s_a = 2163 - 1841.6 = 321.7'$

$T_b = 7205 \times 0.291 = 2096.7^k$

A chain length of at least 322' is required & for this length the max. line tension is 2097 kips.

Determine curve characteristics for above parameters.

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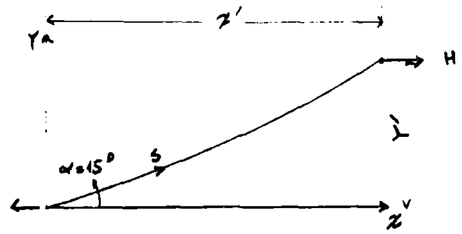
PROJECT: Navy Pier Concepts
ITEM: Instant Anchor for Exp. Pier
DESIGN: chain anchor line
DATE:

SHEET: A-22
OF
REVISION:



Let:
$Y' = 90'$
$L = 322'$
$\alpha = 15°$
$H = 2000^k$
$w_w = 0.291^{k/'}$

$$\frac{dY}{dx} = \frac{w}{H} s + C_1$$

for $s=0$; $\frac{dY}{dx} = \tan\alpha$

$\therefore \tan 15° = C_1 = 0.268$

also $\frac{dY}{dx} = \sinh\left[(x - C_2)\frac{w}{H}\right]$

for $x = 0$; $\frac{dY}{dx} = \tan 15°$

$\therefore C_2 = -1820.2$

$$Y = \frac{H}{w}\cosh\left[(x - C_2)\frac{w}{H}\right] + C_3$$

for $x=0$, $Y = 0$.

$$\therefore C_3 = -\frac{2000}{0.291}\cosh\left[-\frac{0.291}{2000}(-1820.2)\right] = -7115.3$$

$$x = \frac{H}{w}\sinh^{-1}\left(\frac{w}{H}s + C_1\right) + C_2$$

for $s = L = 322'$

$$x' = \frac{2000}{0.291}\sinh^{-1}\left(\frac{0.291}{2000} \times 322 + 0.268\right) - 1820.2 = 309.2'$$

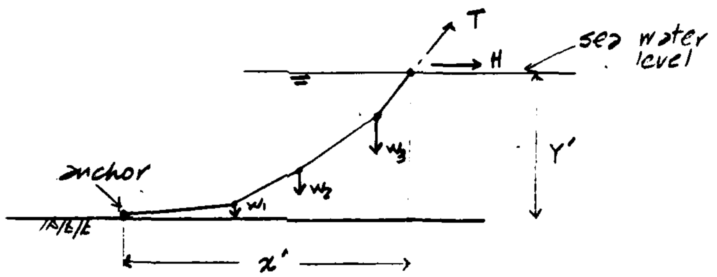
check value of Y'

$$Y' = \frac{2000}{0.291}\cosh\left[(309.2 + 1820.2)\frac{0.291}{2000}\right] - 7115.3 = 90.1' \simeq 90'$$

O.K.

$((x')^2 + (Y')^2)^{1/2} = (309.2^2 + 90.1^2) = 322' \simeq L$ $\therefore$ chain forms nearly a straight line. Desired catenary curve is not achieved. Thus a heavier chain is required.

An alternate to the chain anchor line can be a light rope which has weights suspended at various intervals. The light rope will be easier to handle & also economical. The suspended weights will provide the vertical component to form a catenary curve.



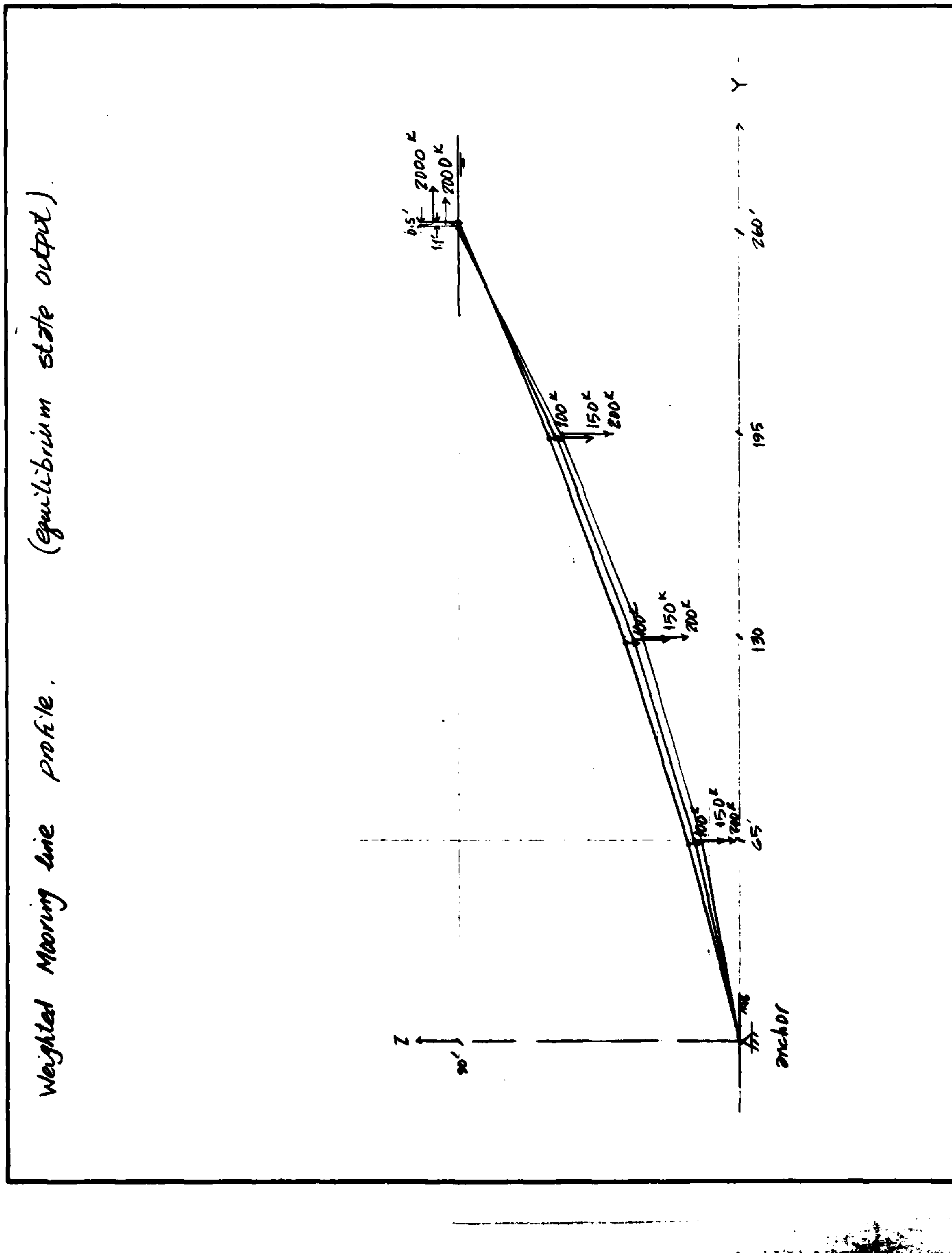
An optimization of the above concept requires to select appropriate weights that will be functional for a range of mooring forces, (say from $H = 500^k$ to $H = 2000^k$). The spacing of the weights will be a function of water depth and also the mooring force. A computer program can be developed to determine the above variables for the prevailing mooring conditions and can be utilized aboard the Exp. Pier.

A sample calculation will be performed here to illustrate the above concept clearly. In order to compare it to the chain line solution, similar design conditions will be maintained.

Materials:

KEVLAR rope : 9, $2\frac{1}{2}$"ϕ strands ; breaking strength = 4000^k
wt. in air ≈ 17.1 lb/ft. & wt. in water ≈ 0.25 × 17.1 = 4.3 lb/ft.

T.Y. LIN INTERNATIONAL STRUCTURAL ENGINEERING 315 Bay St., San Francisco, Ca. 94133	PROJECT: Navy Pier Concepts ITEM: Instant Anchor for Exp. Pier DESIGN: Weighted Mooring Line DATE:
SHEET: A-24 OF REVISION:	



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PROJECT: Navy Pier Concepts
ITEM: Instant Anchor for Exp. Pier
DESIGN: Weighted Anchor Line.
DATE:

SHEET: A-25
OF
REVISION:

Summary:

Load case	Weight ($W_1 = W_2 = W_3$)	Horiz. Force	Max. Tension
1	100^k	2000^k	2166^k
2	150^k	2000^k	2200^k
3	200^k	2000^k	2230^k
4	200^k	3000^k	3280^k

@ sea level $\Delta_{(4-3)} = 1.2$ FT.

Conclusion:

- It is seen that the line tension does not vary much with a change in weights.
- For a horizontal displacement of 2.2 FT at the sea level. The horizontal Force (H) increases to 3000^k, the same force is felt at the anchor also.
- With a suitable arrangement and magnitude of the suspended weights the variation of horizontal force with displacement can be made more insensitive. OR, in other words the mooring line can allow greater horizontal displacements without a considerable increase of force on the anchor

APPENDIX B

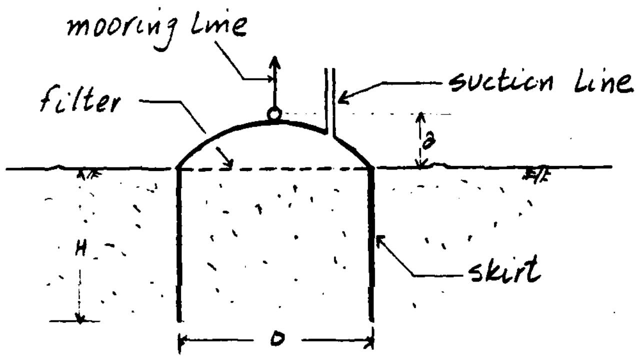
Anchors.

TYLIN INTERNATIONAL STRUCTURAL ENGINEERING 315 Bay St., San Francisco, Ca. 94133	PROJECT: Navy Pier Concepts	SHEET: B-1
	ITEM: Instant Anchor for Exp. Pier	OF
	DESIGN: suction anchor	REVISION:
	DATE:	

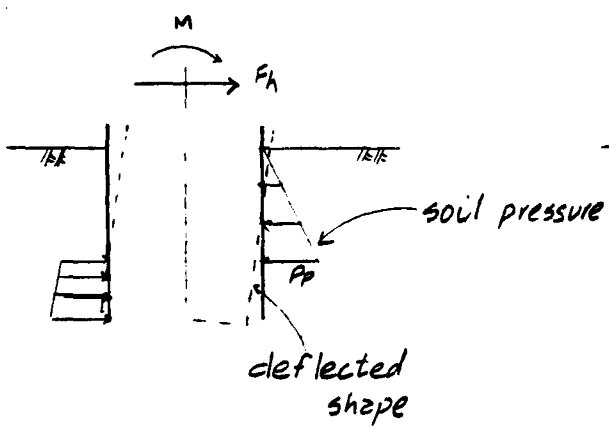
Suction anchors:

In order to determine the feasibility of cup-type suction anchors for the expeditionary pier, a brief parametric study will be made.

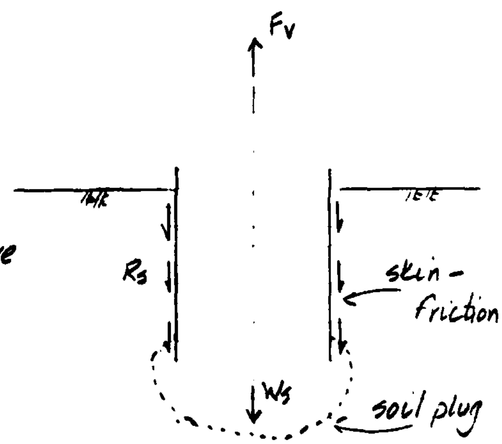
S.O.A. "cup-type" suction anchor:



Failure Modes:



a) Lateral load



b) Pull-out.

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PROJECT: Navy Pier Concepts
ITEM: suction anchors
DESIGN: suction anchor
DATE:

SHEET: B-2
OF
REVISION:

From Brom's equation: (Ref 1)

$$F_h = \frac{\gamma' D H^3 \tan^2(45 + \phi/2)}{2(a+H)}$$

$$F_v = R_s^* + W_s + \text{weight of anchor in water}$$

Assumptions for study:

soil: sand
$\gamma = 130$ Pcf & $\gamma' = (130 - 64) = 66$ pcf
$\phi = 37°$
$f_s = c/2 \simeq 200$ Psf
$W_s =$ (Volume inside pile) $\cdot \gamma' \cdot 1.2$
$a = 3$ ft

TABLE 1.

Dia. (FT.)	H = 10′		H = 15′		H = 20′		H = 25′	
	F_h (Kip)	F_v^* (Kip)	F_h (Kip)	F_v^* (Kip)	F_h (Kip)	F_v^* (Kip)	F_h (Kip)	F_v^* (Kip)
20	204	374	497	561	923	749	1480	936
30	306	748	746	1122	1384	1497	2220	1870
40	408	1246	995	1870	1846	2493	2961	3116
45	460	1542	1120	2313	2076	3085	3331	3355
50	510	1870	1244	2800	2307	3740	3700	4673
55	560	2230	1368	3340	2538	4455	4070	5568
60	612	2616	1492	4166	2768	5232	4442	6540

F_h : does not include base shear contribution

R_s^* : on outside face only (inside face friction reduced).

F_v^* : does not include self weight of anchor

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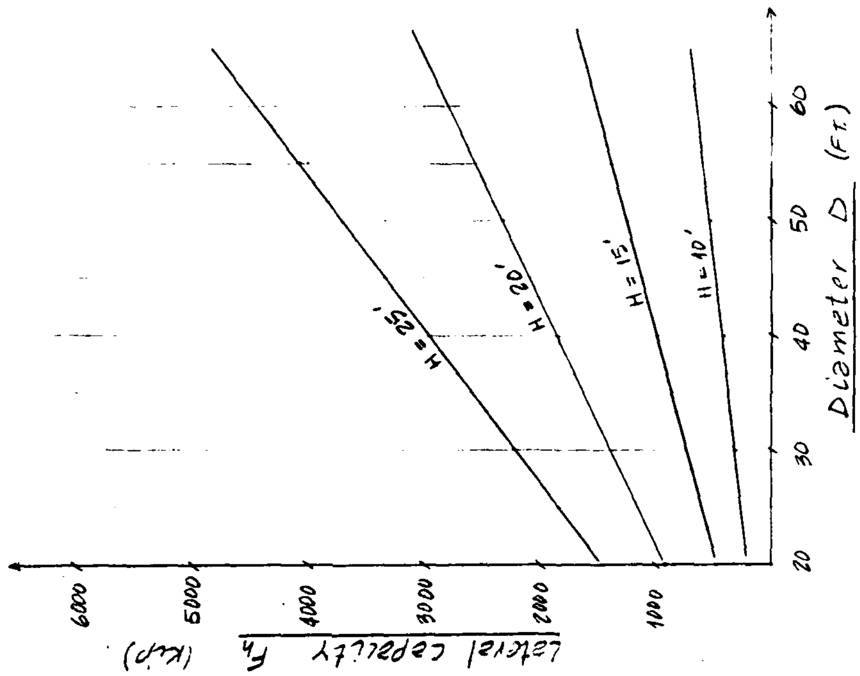
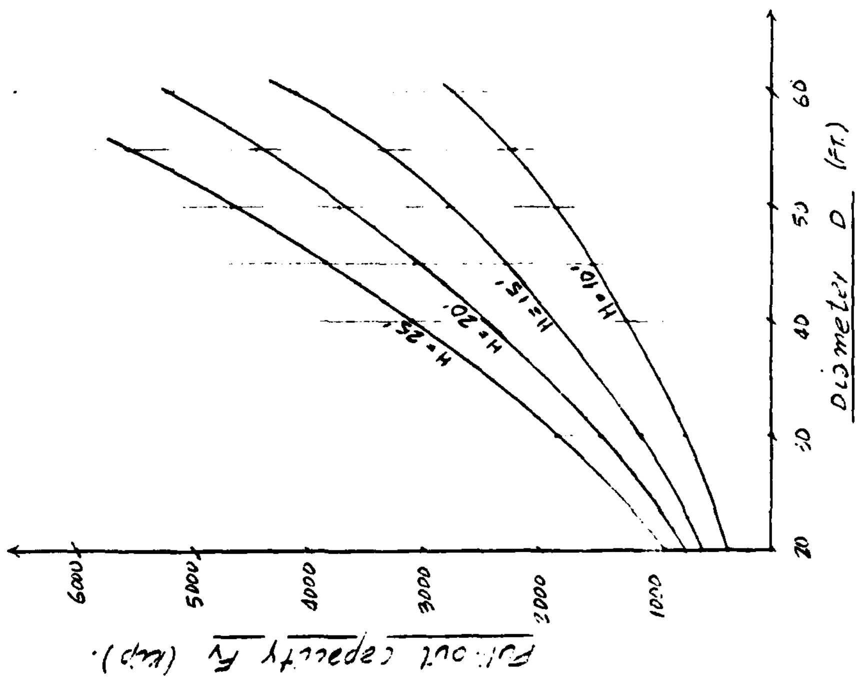
PROJECT:	Navy Pier Concepts
ITEM:	Instant Anchor for Exp. Pier
DESIGN:	Suction Anchor
DATE:	

SHEET: 3-3
OF
REVISION:





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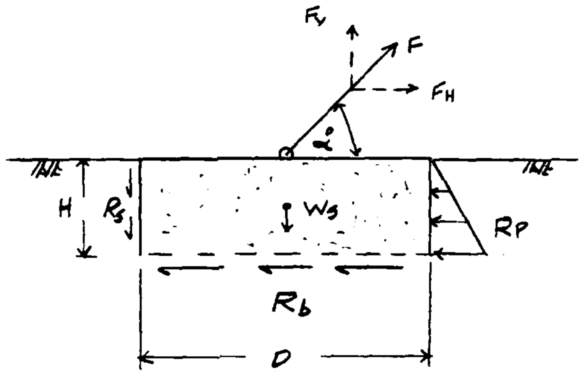
PROJECT: Navy Pier Concepts
ITEM: Instant Anchor for Exp. Pier
DESIGN: SUCTION ANCHOR
DATE:

SHEET: 3-4
OF
REVISION:



R_b = base shear resist.
R_p = passive press. resist.
W_s = wt. of soil plug
R_s = skin friction
F = max. line tension @ ∡α° (k)
F_H = Cap. @ ∡α° (kip)

$F = F_V / \sin\alpha$ ——— 1

OR $F = F_H / \cos\alpha$ ——— 2

$F_V = W_s + R_s$ ——— (computed in Tab. 1)

$F_H = R_p + R_b = F\cos\alpha$

$$F = \left[\frac{\gamma' D H^3 \tan^2(45 + \phi/2)}{2(a+H)} + (W_s - F\sin\alpha)\tan\phi \right] 1/\cos\alpha$$

TABLE 2

α deg	H = 15′				H = 20′			
	Dia = 45′		Dia = 50′		Dia = 45′		Dia = 50′	
	F (k)	F_H (k)	F (k)	F_H (k)	F (k)	F_H (k)	F (k)	F_H (k)
0	2545	2545	3002	3002	3915	3915	4651	4651
2	2480	2478	2927	2925	3875	3872	4535	4532
4	2422	2416	2860	2853	3785	3775	4430	4419
6	2370	2357	2796	2780	3703	3682	4334	4310
8	2320	2297	2140	2713	3630	3594	4247	4205
10	2280	2245	2690	2649	3563	3508	4170	4106
14	2210	2144	2604	2526	3448	3345	4035	3915
18	2150	2044	2535	2411	3356	3191	3929	3736
22	2100	1947	2482	2301	3286	3046	3845	3565
26	2070	1860	2442	2194	3233	2906	3784	3401
30	2047	1772	2415	2091	3198	2769	3742	3240

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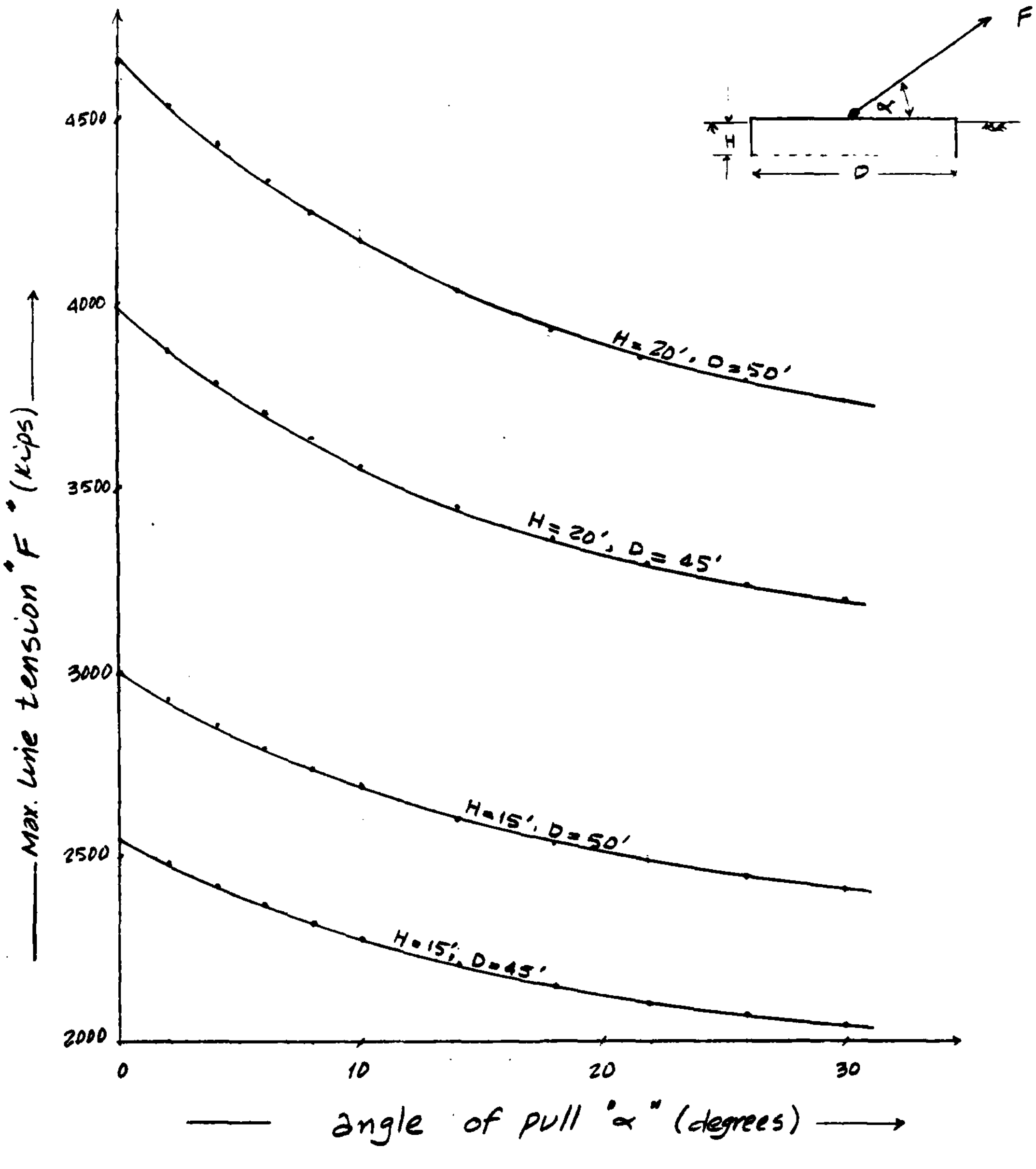
315 Bay St., San Francisco, Ca. 94133

PROJECT: Navy Pier Concepts	SHEET: B-5
ITEM: Instant Anchor for Exp. Pier	OF
DESIGN: suction Anchor	REVISION:
DATE:	



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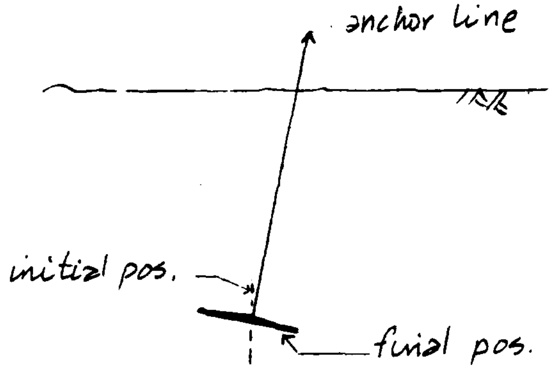
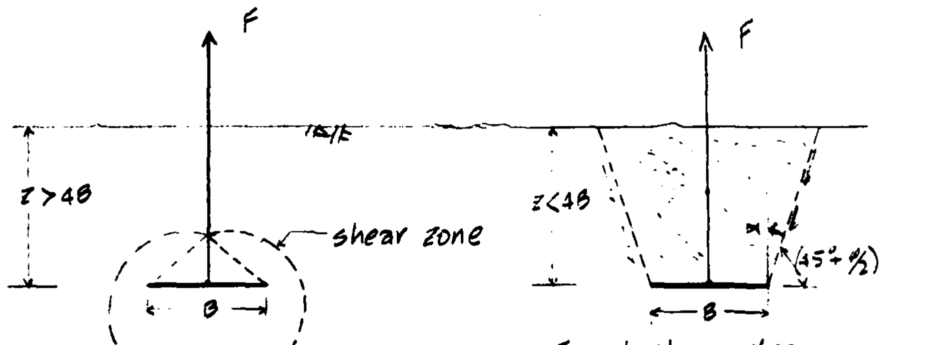
PROJECT: Navy Pier Concepts
ITEM: Instant Anchor for Exp. Pier
DESIGN: Propellant Embedded anch
DATE:

SHEET: B-6
OF
REVISION:

TYP PROPELLANT EMBEDDED ANCHOR



Failure mode:



for $z > 4B$ $\qquad\qquad\qquad$ OR $\qquad F = W_{soil} + \text{shear}$

$F \approx (cN_c + q'N_q)A \qquad F \approx (z\tan\alpha + B)^2 \, z \, \gamma' + 4 \cdot z \cdot c\,(z\tan\alpha + B)$

FOR sands: $(\gamma_w = 130\ \text{pcf},\ \varphi = 37°,\ s = 200\ \text{psf})$

$F_s \simeq q'N_q \cdot A \qquad$ OR $\qquad F_s \simeq 15\,\gamma' z\ A$

$q' = \gamma' z$

$N_q \cong 15 \qquad$ (For local failure)

FOR Clays: $(\gamma_N = 125\ Pcf,\ \varphi = 0°,\ c = 700\ Psf)$.

$F_c = (5c + \gamma' z)\ A$

$N_c = 5$

$N_\gamma = 1$

size / depth (FT)	6'x6' F_s (Kip)	6'x6' F_c (Kip)	8'x8' F_s (Kip)	8'x8' F_c (Kip)	10'x10' F_s (Kip)	10'x10' F_c (Kip)	12'x12' F_s (Kip)	12'x12' F_c (Kip)
10	167	148	215	263	268	412	326	593
15	340	160	423	283	513	443	610	637
20	592	170	715	303	850	474	990	682
25	890	180	1103	323	1285	505	1480	727
30	—	190	—	343	—	536	—	772
40	—	215	—	383	—	598	—	862
45	—	226	—	403	—	629	—	907
50	—	237	—	423	—	660	—	952

conclusion:

- higher capacity can be achieved in sand, but penetration is limited
- difficult to predict pentration & behavior of larger flukes.

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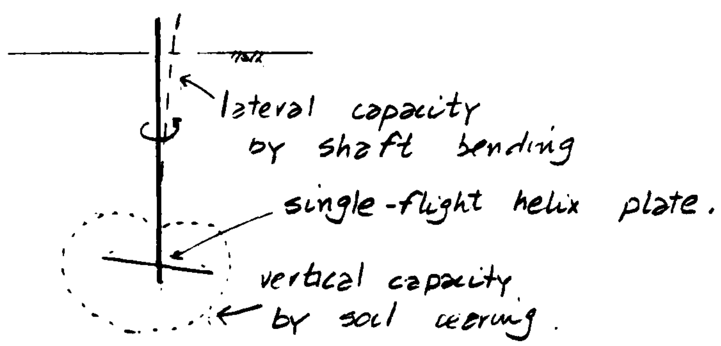
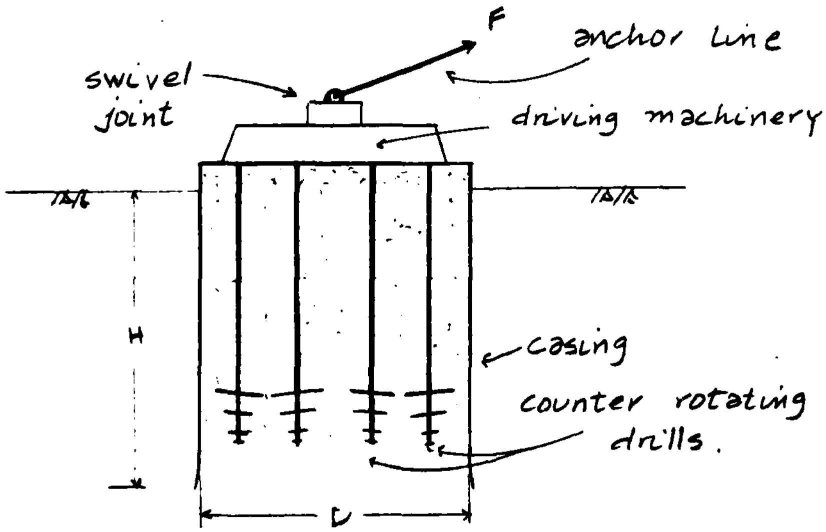
PROJECT:	Navy Pier Concepts
ITEM:	Instant Anchor for Exp. Pier
DESIGN:	Drilled-in Anchor
DATE:	

SHEET: B-8
OF
REVISION:

Typ. low capacity drilled-in-anchor (D.I.A)



Proposed "high" capacity D.I.A:



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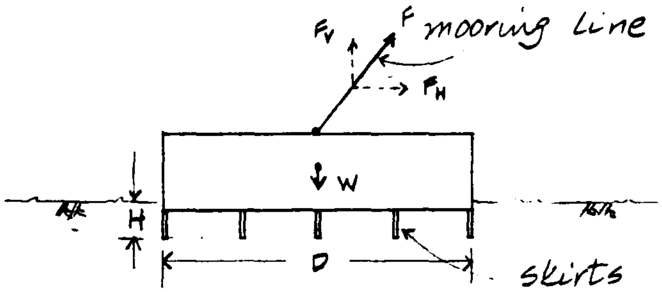
PROJECT: Navy Pier Concepts
ITEM: Instant Anchor for Exp. Pier
DESIGN: Drilled-in Anchor
DATE:

SHEET: B-9
OF
REVISION:

NOTES

- a large H/D ratio may not be achievable
- vertical capacity is obtained by skin-friction, self weight and weight of soil in casing.
- lateral capacity is obtained by passive pressure on the sides and base shear. Behavior may be differant for high H/D.
- holding capacity behavior relative to size (D) and penetration depth (H) is similar to that of suction anchors.

Typ. Deadweight anchor.



The capacity of the deadweight anchor can be estimated in a manner similar to the suction anchor.

$$F = F_V / \sin\alpha$$

$$\text{or } F = F_H / \cos\alpha$$

$$F = \left[\gamma' D H^3 \tan^2(45 + \phi/2) + (W - F\sin\alpha)\tan\phi \right] / \cos\alpha$$

A reasonable way to study the feasibility of the deadweight anchor is to compare it with the suction anchor with similar parameters. The weight required by the deadweight anchor to achieve an equivalent capacity as a suction anchor of same size will be computed.

For: $H = 15'$, $D = 45'$; Cap. $F_H = 2144^{kips}$ @ $\alpha = 14°$
req'd. wt. in water = 1900 kips

$H = 15'$, $D = 50'$ Cap: $F_H = 2526^{kips}$ @ $\alpha = 14°$
req'd wt. in water = 2300 kips

$H = 20'$, $D = 45'$ Cap: $F_H = 3345^{kips}$ @ $\alpha = 14°$
req'd wt in water = 2520 kips

$H = 20'$, $D = 50'$ Cap: $F_H = 4000^{kips}$ @ $\alpha = 14°$
req'd wt. in water = 3110 kips

TYIN INTERNATIONAL
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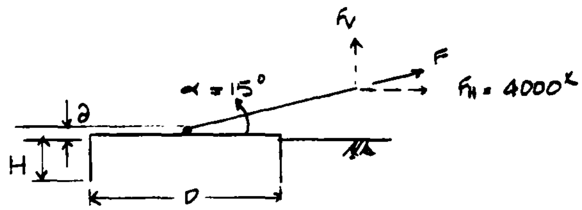
PROJECT: Navy Pier Concepts
ITEM: Self Contained Mobile Anchor
DESIGN: Capacity (SCMA)
DATE:

SHEET: B-11
OF
REVISION:

Obtain dimensions for SCMA based on suction-anchor principle.

Design for 4000^K lateral capacity for defined soil.
Line angle $= 15^\circ$



$F = F_H / \cos\alpha = 4141^K$

$F_V = F \sin\alpha = 1071^K$

$$F_H = \frac{\gamma' D H^3 \tan^2(45 + \varphi/2)}{2(a+H)} + (W_S - F_V \tan\alpha)\tan\varphi$$

Assume:
$\gamma' = 0.066$ KCF ; $\varphi = 37^\circ$; $a = 10'$

Check F_H FOR $D = 80'$ & $H = 15'$

$F_H = \underline{4302^K}$ O.K.

Note:
This does not include self wt. of SCMA OR additional ballast.

TY LIN INTERNATIONAL STRUCTURAL ENGINEERING 315 Bay St., San Francisco, Ca. 94133	PROJECT: Navy Pier Concepts.	SHEET: B-12
	ITEM: SCMA	OF
	DESIGN: Weight.	REVISION:
	DATE:	

Item	weight (TONS)
Concrete	40
Steel:	
Suction Chambers	270
Filter	50
Mechanical equipment & fixtures @ 300 psf	952
Swivel Joint	8
Structural Members	80
Total	1400

1400 Tons in air

Appx. weight in water = 1200 Tons.

Volume of void space required for Neutral buoyancy = $1200 \times \frac{64}{2000}$ = 37500 $FT.^3$